# Core strength or Achilles' heel

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# Core strength or Achilles' heel:
# Organizational competencies and the performance of R&D collaborations

Harmke de Groot

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# Organizational competencies and the performance of R&D collaborations

**Proefschrift**

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To my parents Richard and Betsy,
who don’t always stand behind my choices,
but who never fail to stand behind me.
I hope to pay forward the same kind of unconditional love
to our children Rick and Lisette.

# Summary

Firms engaging in an expensive, risky, and/or complex development commonly rely on partnerships with external knowledge providers to enhance their innovation performance. Academics in strategic and innovation management have long noticed and explored how certain organizational competencies help a firm explore, assimilate, and integrate external knowledge. The literature categorizes these organizational competencies into two parts: component competencies, which are the local abilities and knowledge that are fundamental to day-to-day problem-solving, including all existing technical competencies; and architectural competencies, also called dynamic capabilities, which form the ability to integrate component competencies and to develop new component competencies as required. Thus far, these two types of organizational competencies have largely been studied as separate determinants of innovation performance. This has led to sometimes puzzling and even contradictory results with respect to the benefits of having a high level of in-house component competencies. My dissertation seeks to explain these contradictory results by addressing the interaction effect between the component and architectural competencies, along with the firm's R&D objectives, on R&D partner choice and new product development (NPD) performance. Figure 1 shows the main relationships investigated in this thesis, including an interaction effect between component and architectural competencies. These relationships are examined in three empirical chapters, namely chapters 2, 3 and 4. The three core chapters of my dissertation relate to each other and they complement each other for a more complete picture.

Chapter 1 provides an introduction of the research context, including the conceptual model of the thesis, substantiated with the underlying theories and assumptions based on the literature, and the general methodology. Then it shows the research outline of my three empirical chapters. Finally, it provides an overview of the intended contributions.

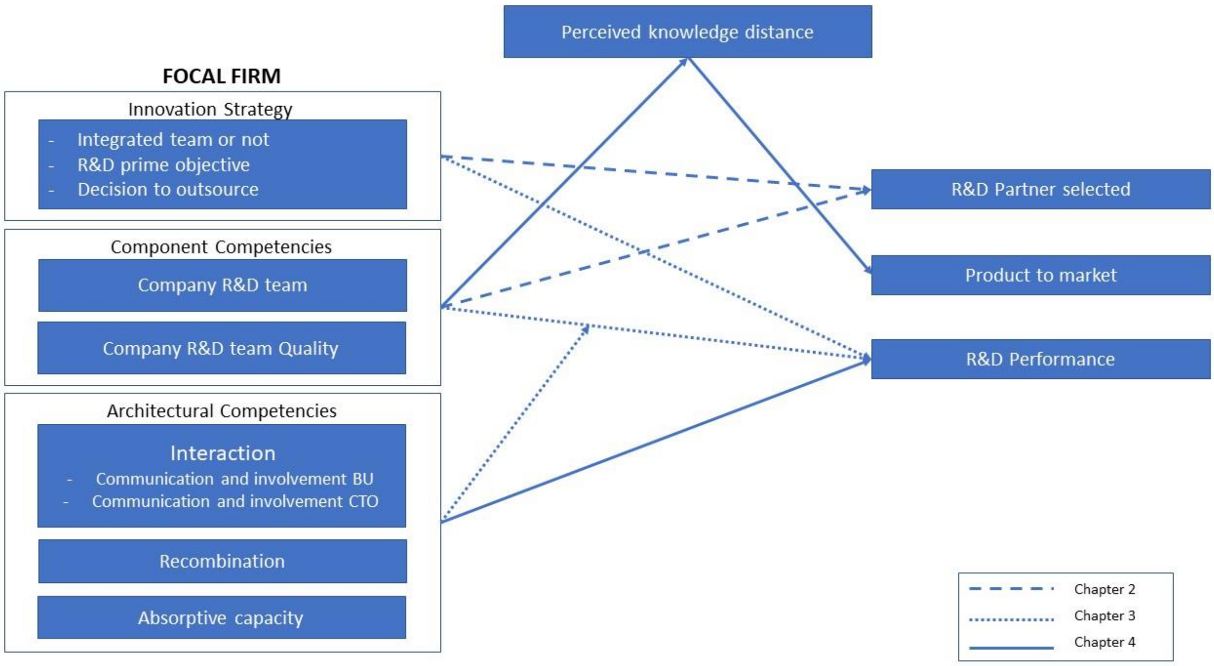


*Figure 1. Main relationships investigated in this thesis*

In this dissertation, quantitative research methods to validate hypotheses are used throughout. These analyses are based on two datasets of finished R&D projects in the semiconductor industry setting worldwide. An online questionnaire, which asked senior people working in the semiconductor industry about their last finalized project, was developed to collect the data necessary to analyze the hypothesis presented in chapters 2 and 4. For Chapter 3, we started with a database that included all R&D projects completed within the Smart Electronics division of Imec, a top-3 worldwide research organization in the field of semiconductor technology, over the 2004-2014 period. Additional data was collected from 10 individuals via individual interviews and questionnaires with Business and Program management.

Chapter 2 investigates how the organizational competencies and R&D prime objective of the focal firm are related with who is seen as the most important partner in the R&D project. While that will often be the focal firm itself, there are circumstances in which a lead customer or supplier will become the most important partner. As this partner will have the upper hand in times of disagreement amongst R&D partners, this study fills a gap in the current literature as we explicitly defined the “most important partner” (MIP) as the organization that dominates the product specification in an NPD project. Based on resource dependence theory (RDT), with complementary aspects of behavioral decision theory (BDT) in times of great uncertainty, the conditions under which a supplier or the customer becomes more important than the focal firm in terms of their control of the product specification are examined. Customers are more likely to be the MIP when they are involved, as they are paymasters, but in R&D projects they are only seen as MIP when they also contribute to bridge a knowledge gap. Projects with the focal firm as the MIP rather than a lead customer have on average a lower knowledge distance and a tendency to prioritize cost optimization. On the contrary, when the highest product performance is the R&D prime objective, and there is an external technology critical for the product performance, a supplier will be relatively more likely to become the MIP. Quite logically, this is also associated with the focal firm pursuing a recombination strategy.

Chapter 3 examines how organizational competencies affect innovation performance of companies when collaborating with an external R&D organization. It starts with a review of a resource-based view (RBV) of the organization, followed by a discussion of different aspects of BDT that complement the RBV to explain how "not-invented-here" practices can hinder effective external knowledge transfer, especially for teams that already have prior knowledge in the area of collaboration. I found that having higher pre-project innovation quality reduces the innovation outcome, making external collaborations less useful for an experienced innovation team, unless their architectural competencies are at the same high level. This study contributes to the literature with a model of the firm explaining unexpected (negative) results of previous studies on open innovation performance. This was done by modeling component and architectural competencies as separate constructs and validating an interaction effect between them.

Chapter 4 is more exploratory and focuses on the relationship of absorptive capacity and knowledge distance with NPD performance. I add to the open innovation literature by examining why absorptive capacity is in fact largely independent to internal technical competencies with respect to its effect on NPD performance during product development. I relate this with the practical notion that most companies nowadays have some form of stage-gated innovation process. I found that project collaborators are selected based on the knowledge distance that the R&D team must confront rather than its absorptive capacity. On the other hand, absorptive capacity was found to be positively associated with NPD performance, independent of knowledge distance. Together with the results of Chapter 2, this leads to an extension of RBV theory with RDT aspects, as this thesis adds the notion that in an environment of omnipresent R&D partnering, a knowledge gap can be bridged by the focal firm or the component competencies of its trusted R&D partners.

The general conclusion Chapter integrates the findings of the three empirical chapters. The intended innovation strategy, component competencies of the focal firm's team, and with that the (perceived) knowledge distance prior to an R&D project startup are instrumental in the selection of its R&D partners and in deciding whether the objective of an R&D project is to determine technical feasibility or create a prototype or a product that would be introduced to the market. In contrast, the innovation performance of the collaborative R&D project after initial partner selection and project start is highly dependent on the architectural competencies including absorptive capacity of the team. This Chapter also discusses the limitations of this thesis and suggestions for future research.

Overall, this dissertation advances our understanding of how organizational competencies and R&D objectives are related with partner selection and R&D performance at the project level. It aims to explicate several key concepts of organizational competencies and collaborative innovation. It expands the traditional RBV with RDT aspects as in a world of omni-present R&D partnering, the component competencies of trusted R&D partners can be seen as part of the focal firm's competencies in certain situations. Practical innovation issues in a real-life (open) R&D environment are also considered. The findings provide guidelines for managers to how they can pay more of their attention to the architectural competencies of their individuals, teams, and organization, in addition to their current efforts to increase the component competencies of individuals, teams, and organization.

# Contents


Chapter 1 Introduction ..... 1

The importance of R&D partners ..... 2

R&D performance ..... 4

Organizational competencies and R&D performance ..... 5

Architectural competencies ..... 6

Component competencies ..... 6

Knowledge distance ..... 7

Innovation strategy and R&D performance ..... 8

Conceptual model and outline of the thesis ..... 9

Underlying theories ..... 11

Underlying assumptions ..... 12

Empirical settings ..... 14

Types of R&D projects done in the semiconductor industry ..... 15

Methodologies ..... 17

Intended contributions ..... 18

Chapter 2 Customer is King, but when to bow to a supplier?: Explaining the most important partner in product development ..... 21

Abstract ..... 21

Introduction ..... 22

Literature and concepts ..... 25

MIP in NPD: lead customer, focal firm internal, and critical supplier ..... 25

The R&D prime objective: four different priorities ..... 26

Priority 1: Cost optimization ..... 27

Priority 2: Superior product quality ..... 27

Priority 3: Time to market ..... 27

Priority 4: Build-up of internal competencies ..... 27

Knowledge distance ..... 28

External knowledge use: recombination ..... 29

Hypotheses ..... 30

Customer as MIP ..... 31

Knowledge distance ..... 33

Recombination ..... 34

R&D prime objective ..... 35

Data and Method ..... 37

Data collection and characteristics ..... 37

Operationalization of variables ..... 40

Outcome variable ..... 40

Independent variables ..... 40

Regression methods ..... 42

Results ..... 43

Validity of the model ..... 47

Discussion ..... 48

Customer as MIP ..... 48

Supplier as MIP ..... 49

Theoretical implications ..... 50

Limitations and future research ..... 52

Conclusions ..... 54

Acknowledgments ..... 54

Appendix 1: Parameter, construct, and source of questions ..... 56

Appendix 2: Results of multinomial logistic regression ..... 59

Variables ..... 59

Results Stata ..... 60

Appendix 3: Validity of the model, Hausman and single respondent tests .............62

Chapter 3 Close collaboration matters:
Relating organizational competencies with external knowledge transfer and use..................69

Abstract .....................................................................................................69

Introduction .................................................................................................70

Literature & hypotheses ..............................................................................72

Innovation outcome & knowledge transfer ...........................................................72

Not-invented-here syndrome .....................................................................73

Architectural competencies .........................................................................74

Breadth and frequency of interaction .........................................................74

Recombination ...........................................................................................75

Component competencies ..........................................................................75

Integrated R&D team ..................................................................................76

Method ........................................................................................................81

Results .........................................................................................................87

Innovation outcome of R&D projects without residents .................................88

Innovation outcome of R&D projects with residents .....................................89

Robustness tests and other considerations ...................................................93

Discussion ...................................................................................................95

Limitations and future research ..................................................................100

Managerial implications .............................................................................101

Conclusions ...............................................................................................104

Acknowledgments .....................................................................................104

Appendix 1: Imec project database: additional data collected ........................106

Appendix 2: Detailed OLS results ...............................................................108

Chapter 4 Fill up the knowledge gap or build a bridge:
Knowledge distance and absorptive capacity ................................................113

Abstract .....................................................................................................113

Introduction ........ 114
Literature and concepts ........ 117
R&D partners ........ 117
Absorptive capacity ........ 117
Knowledge distance ........ 119
The gated innovation process:
pre-product R&D projects versus product development ........ 119
New product development performance ........ 121
Hypotheses ........ 121
Data and method ........ 127
Data collection and characteristics ........ 127
Operationalization of variables ........ 131
Outcome variables ........ 131
Independent variables ........ 132
Control variables ........ 132
Data analysis ........ 134
Results ........ 138
Discussion ........ 141
Theoretical implications ........ 141
Limitations and future research ........ 146
Managerial implications ........ 147
Conclusions ........ 148
Acknowledgments ........ 149
Appendix 1: Definitions, parameters, and sources of questions ........ 150
Chapter 5 Main findings and conclusions ........ 157
Practical implications ........ 164
Limitations and suggestions for future research ........ 165

Endogeneity bias ........ 165

Sender and receiver behavior ........ 168

Quality of the R&D team ex-ante the R&D project ........ 168

Causal inference ........ 169

Project level versus company level innovation pipeline and partnerships ........ 169

Financial and risk implications ........ 170

Conclusion ........ 170

Bibliography ........ 173

Acknowledgements ........ 183

About the author ........ 187

# Chapter 1
# Introduction

In my former role as a Research & Development (R&D) director at the research organization Imec, we worked with many high tech organizations from all around the world. Imec, as an independent top-3 worldwide R&D organization in semiconductor technology, delivers an open innovation environment in which R&D partners work together in coopetition (collaboration in R&D, competition in the market place). The semiconductor industry is exceptionally large, investing more than 35 billion dollars in research and development and is known for its pronounced division or separation of functions in the semiconductor value chain. A major driving factor in the semiconductor industry has been the cost reduction of about 25% per annum for a certain number of transistors (translating in a certain amount of functionality) on an integrated circuit (IC), driving ICs to become increasingly more complex and functional every generation to keep sales prices more constant. In dealing with this ever-increasing complexity of designs, almost all R&D projects in this industry are done with one or more external R&D partners and the use of external intellectual property (IP) blocks, modules copied into one's IC design without knowing the exact details of what is inside, is common. In Imec, we set up many multi- as well as individual R&D partnerships with companies from all around the world. I noticed that the most successful partnerships in terms of innovation outcome were not always, as I expected, with companies that had a technical DNA close to Imec's. Indeed, technical specialists on both sides knew the technical content and used similar tooling; hence, they should have worked together effortlessly. In practice though, it did not seem to work that way. We experienced that some innovation projects that showed a "perfect match" between the technical background of the industrial partner's team and Imec's team progressed much slower than expected. Some companies seemed to be much better in exploring, assimilating, and integrating external knowledge. It became clear to me that besides technical competencies, there must be other organizational competencies that help to benefit effectively from collaborative forms of R&D. For expensive and complex R&D projects, like those designed in, for example, semiconductor industry, pharma, automotive, and health care, interfirm collaborative R&D, which includes suppliers, research organizations, universities, and in many cases also customers, is the norm. Thus, it is a major competitive advantage for a company to be able to optimize the innovation outcome when working with external R&D partners. I found out that current day literature on R&D

partnerships is mainly based on two categories of theory: the resource based view (RBV), which argues that a firm's valuable, rare, socially complex, and inimitable resources generate a competitive advantage (Henderson & Cockburn, 1994; Wernerfelt, 1984), and the resource dependency theory (RDT), which focuses on how firms manage uncertainty and mitigate the effects of external forces to enhance their innovation performance. In literature about open innovation, the RBV is often taken and it focuses very much at firm internal aspects. It describes internal R&D and external R&D partnering as complementary aspects, rather than possible replacements of each other (Miotti & Sachwald, 2003; Rosenberg, 1990). This in itself however cannot explain why some companies without much technical competency in a certain field are still much better in using external knowledge from R&D partners than others are with high levels of internal technical competency. This does suggest that external R&D and internal R&D can be replacements of each other. It also does not explain the dynamics around which partner becomes more powerful and hence can better negotiate when there are multiple R&D partners. I investigate these questions further in this thesis. I found that for theorizing the importance of R&D partners RDT (Pfeffer & Salancik, 1978) provides valuable insights. Firms are constrained by and depend on other organizations that control resources that are critical for them according to this view. In a world where R&D partnering is omnipresent both RBV and RDT theories come together and the final innovative performance of a firm becomes dependent on both their internal inimitable resources as well as how well they are able to use external inimitable resources. Even though academic scholars had clearly long noticed before I did that firms have non-technical competencies which greatly enhance effective external knowledge use (Dyer & Singh, 1998) and open innovation was a popular paradigm (Chesbrough, 2003, 2006; Chesbrough & Garman, 2009), the little quantitative literature there was on open innovation described unexpected -and sometimes negative- effects (Poot, Faems, & Vanhaverbeke, 2009; Praest Knudsen & Bøtker Mortensen, 2011). This inspired me to study how organizational competencies and R&D objectives relate with innovation performance in an environment where R&D partnerships are inevitable because of the complexity and/or cost and/or market requirements at hand. The overarching research question of this thesis can hence best be described as: How can firms' develop and leverage organizational competencies to reach their R&D objectives and improve their innovative performance when doing collaborative R&D?

## The importance of R&D partners

Product development usually involves internal R&D of the focal firm, i.e. the company that brings the product to the market. The role of internal R&D can differ greatly, from a very small contribution to defining and developing every aspect of the product in-house. Firms that conduct expensive, risky, and/or complex R&D are increasingly relying on collaboration with external sources of expertise to maintain or even increase their innovation performance (Cassiman & Veugelers, 2002; Morgan & Berthon, 2008). Steadily increasing complexity and development costs in high-tech industries ensured that the external partnership strategy was here to stay.

The open innovation literature (Chesbrough, 2006) sees suppliers, customers and universities as the most important external partners. (Laursen & Salter, 2006) include competitors, consultants, and research institutes. This study focuses on collaborative R&D as seen from a focal firm and hence includes the following categories of partners: internal R&D (and other focal firm internal parties), customer, supplier, university, research institute or other when not defined by the previous five.

The innovation literature acknowledges that working with external R&D partners in New product development (NPD) can be an enduring source of competitive advantage (Cassiman & Veugelers, 2006) and that more than 80% of NPD in pharmaceutical, information technology, and semiconductor industry is done with one or more external R&D partners (Hagedoorn, 2002; Hagedoorn, Link, & Vonortas, 2000; Schuhmacher, Germann, Trill, & Gassmann, 2013). However, less attention has been given to the relative role of such partners. The basic assumption is that the focal firm, being the party that is in the owner of the product specification and usually in the lead to invite the other R&D partners, is the partner that has the decision power in case of disagreement. However, this power balance is much more dynamic. According to the Resource Dependence Theory (RDT), firms attempt to manage uncertainty and mitigate the effects of external forces in order to enhance their performance (Pfeffer & Salancik, 1978). Following the logic of RDT, the success of a firm’s innovation strategies depends on perceived environmental conditions and relationship-based strategies (Atuahene-Gima & Li, 2004; Li & Atuahene-Gima, 2001). That is, a focal firm will try to enhance its innovative capability by coping with dynamic relationships. This means that a focal firm will look dynamically into relationships and will give up part of its decision power in favor of a strong external R&D partner when they assume the benefits of such partnership are crucial to their product success. In current literature around R&D partners little is known about which R&D partner is seen as most important by the focal firm and who can use it power to dominate the product specification in times of disagreement, especially when multiple R&D partners are involved. This is an evident gap in the current research, as the product specification is the anchor of the new product development outcome and affects its success or failure. To address this gap, this thesis defines the partner who is able to dominate the product specification as the most important partner (MIP) in view of the focal firm, which due to its focal product, is in the lead for the selection of the R&D partners. Noordhoff, Kyriakopoulos, Moorman, Pauwels, and Dellaert (2011) showed that greater customer-relation specific investments in a focal firm are associated with more positive innovation relationship. Greater investments reduce customer opportunism and increase the ability to offer valuable insights into the innovation process. Therefore, it is expected that when a customer is involved as a paymaster, this customer will automatically become the MIP. In Chapter 2, we model and validate the circumstances under which the focal firm sees a key customer or critical supplier as MIP instead of themselves.

## R&D performance

Once upon a time R&D was considered to be a creative and unstructured process and control was limited to setting budgets and periodical peer-reviews (Roussel, Saad, & Erickson, 1991). In the 1990s however the business environment changed drastically, most notably in terms of technology fusion and proliferation, shortening of product life-cycles, intensified competition, and this pushed the interest of executive management to increase R&D efficiency by measuring and assessing R&D performance (Kerssens - van Drongelen & Bilderbeek, 1999; Ortt & Smits, 2006). Having a better return on investment on R&D than other companies has become crucial. When an R&D project aims at product development, R&D performance can be measured in terms of product quality, development speed and development cost (Griffin, 1993). In this case, R&D performance is equal to new product development (NPD) performance.

R&D performance cannot be measured in the same way for R&D projects that aim to develop new knowledge, proof feasibility or to make a prototype. When a firm is working together with one or more external R&D partners in that case, the overall success of the collaboration can be seen as the innovation outcome (IO) at the end of the project versus the technology base at the start of the project. This IO includes not only direct IP generation, but also tacit knowledge and the learning of new component competencies. For a research collaboration, as is the focus in Chapter 3, it is hence determined by many factors, including: the use of the collaborative project’s tangible and intangible results in the focal firm’s further research and/or product innovations; the IP which has been created within the external research project and transferred to the focal firm; and the focal firm’s subsequent product development projects showing improved performance, time to market, risk and/or cost reduction.

In Chapter 3, we will operationalize the innovation outcome of research projects done by many different firms with one single research organization and investigate how IO is related with organizational competencies and innovation strategy. In Chapter 4 we will investigate how organizational competencies are related with the decision to start actual product development and with NPD performance.

## Organizational competencies and R&D performance

In a resource-based view, RBV, the possession of unique 'competencies' or 'capabilities' is an essential source of enduring strategic advantage (Cohen & Levinthal, 1989; Dyer, 1997; Wernerfelt, 1984). Henderson and Cockburn (1994) described heterogeneous organizational competencies, which they divided into component competencies and architectural competencies, and noticed that they could explain a significant part of the variance in R&D performance. They defined component competence as local abilities and knowledge that are fundamental to day-to-day problem-solving, including all existing technical competencies, and architectural competencies as the ability to use these component competencies and integrate them effectively to develop fresh component competencies. Architectural competencies include dynamic capabilities, as delineated by (Dyer, 1997) and (Gassmann, Enkel, & Chesbrough, 2010). Both types of competencies might lead to a competitive advantage, but architectural competencies are especially helpful in building up and transferring from outside new knowledge absent specific knowledge of the particular domain of R&D.

Dealing with external knowledge is not trivial, as many studies have found that a negative attitude towards knowledge sharing prevails (Dyer, Kale, & Singh, 2001; Eisenhardt & Martin, 2000; Expósito-Langa, Molina-Morales, & Capo-Vicedo, 2011). For collaborative R&D, architectural competencies seem to be of essence in dealing with external knowledge transfer, while component competencies relate with the performance of the focal firm’s R&D team and also when and with what kind of partners the local firm will collaborate. Hence, this thesis focuses on both architectural as well as component competencies in relation to R&D performance.

**Architectural competencies**

Architectural competencies have been broken down into several measurable aspects, including interaction,  absorptive capacity and recombination competence. The first aspect, interaction, is an indication of more communication and distributed decision making. In Henderson's (1994) paper special attention is paid to the communication and spread of information within a company. This paper found support that companies that have better internal communication and broader spread of information as well as a distributed way of decision-making are more successful in absorption of architectural or integrative improvements. The second aspect of architectural competencies, absorptive capacity, is a collection of four distinct but complementary capabilities (Zahra & George, 2002): acquisition, assimilation, transformation and exploitation. Absorptive capability is presented by them as the architectural competence that influences the creation of other organizational competencies. Hence, in the context of knowledge creation and external knowledge transfer absorptive capacity is a key concept, which we operationalize in Chapter 4 of this thesis.

The last component of architectural competence investigated in this thesis is the ability to recombine at the focal firm. There are three main strategies of using external knowledge, namely internal: any external knowledge used mainly has to fit in the internal knowledge without much adaptation; replication: external knowledge is integrated as is, internal technology will be adapted to fit the external knowledge (Szulanski, Cappetta, & Jensen, 2004); and recombination- both internal and external knowledge are significantly adapted to co-develop a new technology solution (Gruber, MacMillan, & Thompson, 2012). Literature shows that recombination of knowledge within a firm when done correctly is an important source of firm innovation and competitive advantage (Grant, 1996; Grant & Baden-Fuller, 2004; Rosenkopf & Nerkar, 2001). It is also the most difficult form of using external technology as recombination needs the integration of tacit knowledge, socially embedded routines and sticky knowledge and this is difficult to transfer and to master (de Jong & von Hippel, 2009; Mahoney & Williams, 2003; Roussel et al., 1991; Szulanski & Jensen, 2006; Von Hippel, 1978). Therefore, recombination competence is another pillar of architectural competencies that we assume to be crucial to optimize R&D performance when internal R&D works with external R&D partners.

**Component competencies**

A number of researchers have suggested that locally embedded knowledge and skills, also known as component competencies, are a source of enduring competitive advantage for a firm (Dyer, 1997; Kahn, Barton, & Fellows, 2013; Kerssens - van Drongelen & Bilderbeek, 1999). In the field of high tech and pharmaceutical research, these component competencies offer two important possibilities: 1) unique disciplinary expertise and 2) application, process, or other domain-specific knowledge. Component competencies are as such a good indication of the quality of the internal R&D team in their areas of expertise. While many studies have suggested that high component competencies also help to absorb external knowledge in that particular disciplinary area, other studies have suggested that having high component competencies within the field of the external research partnership does not necessarily mean that the knowledge emerging from this R&D effort is easily assimilated and integrated within the NPD of the company (Burcharth, Knudsen, & Søndergaard, 2014; Dyer et al., 2001). On the contrary, some studies have suggested that teams might take up less external knowledge when they are more competent themselves. In earlier research on innovation strategy, including organizational competitive advantages, this phenomenon has either not been addressed (Agrawal, Cockburn, & Rosell, 2010; Grosse Kathoefer & Leker, 2010; Laursen & Salter, 2006) or it has been addressed but with the underlying mechanisms being described in a rather anecdotal fashion (Kathoefer & Leker, 2012). In Chapter 3, we investigate the impact on innovation performance of component and architectural competencies, and especially look at the role of high component competencies before the start of the R&D project and how they are moderated by architectural competencies. In Chapter 4, we investigate the impact on innovation performance of absorptive capacity.

## Knowledge distance

Knowledge distance determines how close the firm's knowledge base, as part of the component competencies, is related to the new technology that it seeks to obtain from an external R&D partner (Peeters, 2013). This will also influence the ease in which new knowledge is integrated with prior knowledge. At least a fraction of new knowledge needs to be related to prior knowledge within the focal firm to be able to absorb the new knowledge (Cooper, 1994). Before the search for partners is started, the focal firm will assess the knowledge distance between their internal competencies and the new technology needed in the project. The product management team with the internal R&D team assesses the KD between the own internal R&D unit and the new technology needed in NPD. When the perceived knowledge distance is high, it is more likely that the internal R&D unit will look for R&D partners that can bridge the gap. When the knowledge distance is low, it is more likely that the internal R&D unit can easily bridge the gap themselves. Therefore, we assume that there is a relation between KD and the choice of partners but also between KD and the decision to start actual product development, versus doing a feasibility study or building a prototype, and we will investigate this relationship further in Chapter 2 and Chapter 4.

### Innovation strategy and R&D performance

Besides organizational competencies, the innovation strategy of a firm will influence the R&D performance and hence is taken into account in our empirical investigations. The focal firm will try to optimize its product profits as well as its R&D resource usage. There is always a trade-off to be made, and the focal firm will use their innovation strategy to evaluate all NPD choices. This will be no different when evaluating if and how to integrate new knowledge in NPD. There are five main different innovation strategy priorities for a project, namely overall lowest cost , superior product quality, shortest time to market, build-up of internal R&D competencies, or insufficient internal resources available (Rechtin & Maier, 1997). The most important innovation strategy priority for a specific project is known prior to the start of the project and is expected to influence R&D partner selection and to moderate the effect of organizational competencies. The decision to engage in R&D partnerships in the first place is linked to the firm's prior choice to carry out its own R&D (Piga & Poyago-Theotoky, 2004). Hence, for all new technology introduced in the NPD trajectory the focal firm will decide to develop or acquire based in large part on its innovation strategy and the availability and quality of their own R&D.

Similarly, the focal firm has an explicit strategy on the use of integrated R&D teams, i.e. teams where the focal firm's internal R&D members and the external R&D partner members become complete integrated and managed as one R&D team with common objectives and physical co-location. Having an integrated R&D team is expected to strongly increase the tacit knowledge transfer and to lower organizational boundaries significantly, but at a high cost and at a risk of spilling over knowledge and know-how to the external R&D partners that the focal firm will not profit from. In this thesis, we investigate how these three aspects of innovation strategy of the focal firm: 1) most important innovation criterion for a project, 2) decision to outsource and 3) use of an integrated R&D team or not, relate with the selection of R&D partners and moderate the effects of organizational competencies.

## Conceptual model and outline of the thesis

The three chapters, which constitute the main body of the dissertation, consider: the relationship between organizational competencies, the R&D prime objective, and who is the most important partner (focal firm, customer, supplier) in a R&D project; the relationship between organizational competencies on the innovative outcome of collaborative R&D projects with a research organization; and how perceived knowledge distance and absorptive capacity of the firm relate with the decision to start actual product development after the study and prototyping phase, and once product development starts, with the new product development performance.

Each Chapter can be read as an individual essay on its own, but together, they also provide more general insights into how a firm's component and architectural competencies together with aspects of their innovation strategy relate with their R&D performance.

Figure 2 shows the main effects investigated between the three core chapters and the ways in which the different chapters complement each other to provide a more complete picture of how a firm's organizational competencies and innovation strategy relate with the selection of R&D partners and with R&D performance in multi-partner R&D projects.

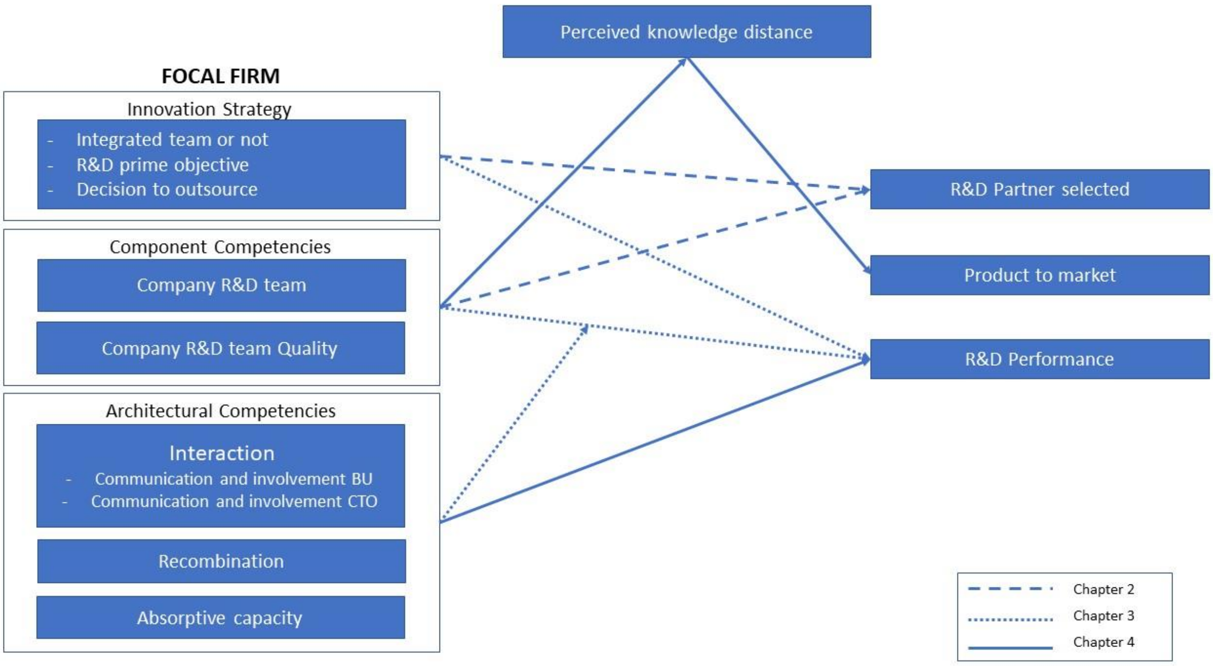


*Figure 2. Main effects investigated in the core chapters*

Chapter 2 investigates the association between organizational competencies, the R&D prime objective, and which type of partner will be seen as the most important by the focal firm. If the most important partner is not a unit of the focal firm itself but a customer or a supplier, this partner will be able to dominate parts of the product specification in times of disagreement between partners. As the product specification forms the basis of the outcome of any NPD process, this study fills a gap in current literature by explicitly defining the "most important partner" (MIP) as the organization that dominates the product specification in an NPD project. We theorize the conditions in which a supplier or the internal R&D team become more important than a customer in terms of their control of the product specification and timeline. The framework draws on resource dependency theory (RDT) using aspects of behavioral decision theory (BDT), specifically rule-based decision making in times of uncertainty (Cyert & March, 1992).

Chapter 3 examines the relationship between organizational competencies and innovation performance of companies that work with an external R&D organization. It starts with a resource-based view (RBV) of the organization, complemented by aspects of BDT to explain how not-invented-here practices can hinder effective external knowledge transfer, especially for teams that already have prior knowledge in the area of collaboration. This study contributes to the literature with a model of innovation project decisions that also explains unexpected (negative) results of previous studies on open innovation performance. We do this by modeling component and architectural competencies as separate constructs and validating an interaction effect between them. The essay shows how the management can take measures to increase the chances of successful collaboration by creating an integrated (multi-firm) R&D team with common objectives and management and physical co-location, which, although not very cost-effective, can be a necessary option when architectural competencies are lower in the firm. The second recommendation to managers is given to make sure that they understand the team's architectural competence, which is often less explicit than the team's component competence.

Chapter 4 focuses on the relationship that absorptive capacity and knowledge distance have with NPD performance. We add to the open innovation literature by showing that absorptive capacity is in fact largely independent from internal technical competencies with respect to its association with NPD performance. On the other hand, we find that the selection of the project collaboration partners depends on the perceived knowledge distance that the R&D team needs to confront rather than its absorptive capacity. During product development, absorptive capacity is positively associated with NPD performance, independent of knowledge distance. These findings combine RBV with an element of RDT dealing with critical partners: the knowledge distance that the focal firm sees itself confronted with can be overcome with its internal component competencies or -when the focal firm has sufficient absorptive capacity, with the external component competencies of its trusted critical partner(s). Hence, the component competencies can be seen as the internal component competencies plus the ones to the focal firm's disposal at their trusted critical partner(s).

## Underlying theories

Overall, this dissertation advances our understanding of the ways in which organizational competencies and innovation strategy relate with partner selection and R&D performance at the project level. Given the complexity of partner selection decisions and later knowledge sharing and transfer behavior of teams, a single theory approach would simply not be suitable for such a complex phenomenon. Therefore, this thesis builds on combining elements from multiple theories. It expands a resource-based view with resource dependency theory while using some aspects of behavioral decision theory to describe how organizational competencies and innovation strategy relate with partner selection and innovation performance. The RBV view takes into account organizational competencies as a means to build an enduring competitive advantage and this thesis expands this with aspects of BDT whereby humans have limited attention span and mainly make rule-based decisions in the uncertain and complex environment that is high tech industry. Therefore, as described in the literature, humans intrinsically have a negative attitude towards knowledge sharing outside their own group if it costs them time and effort without a clear return. RDT on the other hand stresses that the environment and other external forces can determine how firms organize themselves to compete in the marketplace (Hillman, Withers, & Collins, 2009; Pfeffer & Salancik, 1978). According to RDT, firms attempt to manage uncertainty and mitigate the effects of external forces in order to enhance their performance. When firms are constrained by and depend on other organizations that control resources that are critical for them they will build relationships to increase their power and obtain access to these external resources (Li & Atuahene-Gima, 2001). This leads to different behaviors when it comes to critical partners, compared to simple cost economics (Gulati & Sytch, 2007). Last but not least, according to bounded rationality, individuals also take into account only a limited set of decision factors at any given point in time (Griffith & Harvey, 2004), and in times of uncertainty, decisions mainly become rule-based (Gomes-Casseres, 1997). Hence, it is important to understand how the organizational culture and competencies as well as management strategy influence individual and team behavior when collaborating on new technology and knowledge. This thesis explicates several key concepts of competence and collaborative innovation. It also considers practical innovation issues in a real-life (open) R&D environment. Overall, this dissertation advances our understanding of how organizational competencies and innovation strategy relate with partner selection and R&D performance at the project level. Using the underlying combination of RBV and RDT theories, this thesis advances our understanding of how organizational competencies relate with partner choice and innovation performance in a collaborative R&D environment.

## Underlying assumptions

The main assumptions of this dissertation are seven-fold. The first assumption, as mentioned earlier, is that most people are by nature not automatically inclined to share knowledge outside their own team or to go out and learn new knowledge from outside of their own team either within or outside their own organization. To learn and/or to share knowledge is an investment in terms of time and effort, which cannot be spent on other work. “Not invented here” or “not shared here” syndrome, as well as professional pride and/or fear of unwanted information leakage, can all work against a free and open knowledge flow (Burcharth et al., 2014). Second, R&D projects are not one-off projects, but in complex innovation environments, they are part of a gated innovation process, as described by (Gann, 2005) and practiced in some form in the most complex international R&D organizations. This has several implications. It means that the selection of partners is not a one-time effort but something that happens repeatedly across several stages of the innovation process. It also means that decision-makers know quite well the stage of the innovation process in which they are, and they know what they believe to be is the prime R&D objective of a new R&D project before the start of a project. Sometimes, the main aim of a project is simply to build internal competencies for the future, which will lead to very different decisions in terms of partnerships, as opposed to when the main aim of an R&D project is cost reduction or the highest product performance. The third assumption is that in practice, not only product management and procurement, but also the applicable internal R&D team is part of the partner selection process, as the internal R&D team is often the only one that can validate the technical competencies of the external R&D partner. The internal R&D team also influences the prior decision to do in-house R&D versus outsourcing (part of) the work through different ways in which they represent the (technical) case to the decision-makers (usually the product management team).

The fourth assumption is that R&D managers, in general, understand the component competencies, including the technical competencies, of their own teams quite well but pay less attention to and have less understanding of the architectural competencies of their teams and the organization in general (Lindgren, Henfridsson, & Schultze, 2004). The fifth assumption is that with the exception of a lead customer, where the customer, as the paymaster, might be able to enforce upon the focal firm to include certain partners, the selection of R&D partners is done solely by decision-makers within the focal firm, i.e., the firm that creates the product or service to be sold. The assumption is also that the focal firm can decide to include potential R&D partners in different ways. The focal firm can include an R&D partner to be an integrated part of their own R&D team, sharing R&D roadmaps and technical discussions or – at the other end of the spectrum – marginally include the partner as the provider of one single small piece of completely pre-specified technology. The lead customer is again an exception in certain situations. This assumption will not hold strictly for all suppliers in a time when interfirm agreements are made at the executive level to collaborate with and buy from each other, without any influence of the product team at hand. Still, we believe that the freedom to select a partner still holds sufficiently in most cases as long as we exclude lead customers. In addition, the idea that the focal firm decides is only partly true in practice: of course, the R&D partner will become part of the negotiation and this is a more iterative process than shown in this thesis. Still, also here, we believe that the simplification is still sufficiently true to describe the underlying process and behavior. The sixth assumption is that this freedom of selection and usage is limited by bounded rationality (Griffith & Harvey, 2004). The decision makers will only consider a limited set of elements at any given time, and they do not have the complete information available. This also means that for a new project, they will first consider partners with whom they had a good working relationship during previous projects compared to potential partners outside the known network of the decision takers, except when explicit search activities are undertaken to widen the network of potential partners. Faced with the uncertainties of an incomplete market, (potential) partner, and technical information, the strategic partnership decisions will be rule-based (Gomes-Casseres, 1997). That is, the team will use simple rules to guide its behavior. “Not changing a winning team”, i.e., using an existing coalition of R&D partners that have fulfilled the objectives in a similar prior R&D project, can be an example of such a simple rule. The seventh assumption is that while it is possible to have many R&D partners within one R&D project, not all of these R&D partners exert the same influence. There is always one R&D partner that has the largest influence on the R&D project outcome, specifically in terms of product specification. We call this partner the most important partner (MIP). This can be the internal R&D team or one of the external R&D partners, most notably, the lead customer or a critical supplier.

## Empirical settings

This entire thesis was built on two studies of R&D projects conducted in semiconductor industry settings worldwide. Given the peculiar nature of the semiconductor industry, this section clarifies important characteristics that are useful to understand the remainder of this thesis. A particular class of semiconductor devices, so-called integrated circuits (IC's) or chips, is used in nearly every electronic device. They form the technological backbone of the fast development of consumer electronics, such as televisions, computers, DVD's, and the internet and mobile communications, and they contribute to progress in industrial automation, automotive, and aerospace.

The semiconductor industry is exceptionally large, investing more than 35 billion dollars in research and development yearly. The most important players worldwide are shown in Figure 3. The semiconductor industry is constantly changing. Thus, three out of the current top five players were not part of the top five a decade ago.

**Top 10 Worldwide Semiconductor Sales Leaders**

| | 2016 | | 2017 | | | 2018 | | | 2019F | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Company | Sales ($B) | Company | Sales ($B) | Change | Company | Sales ($B) | Change | Company | Sales ($B) | Change |
| 1 | Intel | $57.0 | Samsung | $65.9 | 48.8% | Samsung | $78.5 | 19.2% | Intel | $70.6 | 1.0% |
| 2 | Samsung | $44.3 | Intel | $61.7 | 8.2% | Intel | $69.9 | 13.2% | Samsung | $63.1 | -19.7% |
| 3 | TSMC (2) | $29.5 | TSMC (2) | $32.2 | 9.1% | SK Hynix | $36.8 | 37.6% | | | |
| 4 | Qualcomm (1) | $15.4 | SK Hynix | $26.7 | 79.5% | TSMC (2) | $34.2 | 6.4% | | | |
| 5 | Broadcom (1) | $15.2 | Micron | $23.9 | 76.7% | Micron | $31.0 | 29.6% | | | |
| 6 | SK Hynix | $14.9 | Broadcom (1) | $17.8 | 16.9% | Broadcom (1) | $18.5 | 3.7% | | | |
| 7 | Micron | $13.5 | Qualcomm (1) | $17.0 | 10.5% | Qualcomm (1) | $16.4 | -3.8% | | | |
| 8 | TI | $12.5 | TI | $13.9 | 11.3% | Toshiba* | $14.9 | 12.1% | | | |
| 9 | Toshiba | $10.9 | Toshiba | $13.3 | 21.9% | TI | $14.9 | 6.8% | | | |
| 10 | NXP | $9.5 | Nvidia (1) | $9.4 | 36.1% | Nvidia (1) | $12.0 | 27.1% | | | |
| Top 10 Total ($B) | | $222.8 | — | $281.9 | 26.5% | — | $327.0 | 16.0% | | | |
| Semi Market ($B) | | $364.0 | — | $445.2 | 22.3% | — | $504.1 | 13.2% | — | $468.9 | -7.0% |

Source: IC Insights (1) Fabless (2) Pure-Play foundry *Includes Toshiba Memory

*Figure 3. Worldwide Semiconductor Leaders*

The semiconductor industry is known for its pronounced division or separation of functions in the semiconductor value chain. It includes companies specializing in semiconductor design; companies specializing in manufacturing; and associated companies specializing in semiconductor assembly, packaging, and testing. Fabless companies, like ARM, sell intellectual property, such as designs, to the companies that are designing and building chips. In the last decade, increasing numbers of consumer companies have started to split off their semiconductor division because they are so cyclic, having high revenues one year and low the next, examples are NXP, the former semiconductor division of Philips, and Infineon, the former semiconductor division of Siemens. Moreover, companies continued the trend of designing ICs to outsource manufacturing, i.e., to become fabless (some still have one or more manufacturing facilities in their own possession but outsource manufacturing of the rest).

A major driving factor in the semiconductor industry has been the cost reduction of about 25% per annum for a certain number of transistors (translating in a certain amount of functionality) on an IC, driving ICs to become increasingly more complex and functional every generation to keep sales prices more constant. This price and innovation pressure can only be handled by economies of scale; hence, we currently see many mergers of companies in this industry, an example is Microsemi acquiring Zarlink. This eco-system explains the development of secondary, or more open innovation markets, according to Chesbrough (2006). The ever-increasing complexity of R&D, together with the cost pressure, explains why in this industry almost all R&D projects are done with external partnering of some kind, providing an ideal environment to look into partnership selection and how organizational competencies relate with innovation performance.

**Types of R&D projects done in the semiconductor industry**

R&D projects done in the semiconductor industry differ widely. The players can be divided into four different categories: equipment companies, semiconductor manufacturers, fabless players, and OEMs. Equipment companies, like ASML, or for example Zeiss, that make (part of) the highly specialized equipment used to that create integrated circuits also called micro- or nano-electronic chips. Their R&D projects focus on machine development but can also focus on process development. Then there are their customers, the semiconductor manufacturers, like TSMC or SK Hynix, which undertake the wafer fabrication, packaging, assembly, and test responsibilities of ICs. Their R&D projects can be divided in process development and optimization projects, design projects (for a customer or as reference IP) or design optimization and projects related to packaging, assembly and test. Their customers are the fabless semiconductor players (who might have one or more production facilities but outsource the remainder of production to semiconductor manufacturers) that focus on design of ICs or complex IP blocks within ICs (like ARM for microprocessors). Sometimes they develop in-house special assembly or packaging methods and usually their R&D projects include the needed software and PCB designs to have a full working (reference) application for their end-customer, the OEMs, who creates a mobile phone, computer, car, data center, X-ray machine, personal health device, etc. out of tens to hundreds of these ICs and the accompanying software together with many other components. R&D projects in the semiconductor industry performed with or for OEMs do not only create the end products. They often include demonstrators, reference designs, or technology prototyping. OEM's often do have their own specific application knowledge, which they keep in-house. For example, radar algorithms to detect objects on the road are the expertise of most car companies, even though they buy the actual radar hardware from fabless semiconductor players (and of course, these players have R&D projects where they develop the hardware and software together to optimize its working).

With such a strong vertical specialization, i.e. companies being an expert in a specific market and/or technical area and the intense drive to make more and more complex ICs, no company in this industry is able to do everything on their own anymore and hence R&D partnering is omnipresent. The role of research organizations like Imec can be seen as a bridge between universities and industry in that they help to transform research results into easier to integrate product results. They can also help firms to build up internal component competencies in domains new to the firm faster. Last but not least they can be seen as a more neutral ground for companies to develop new technologies which multiple companies need to use but which are not differentiators in the market place and expensive or sometimes even impossible to develop individually. Examples include semiconductor process technology, new device principles and materials or standardized communication technologies.

Chapter 2 and Chapter 4 are based on a questionnaire about the last finalized R&D project answered in full by 123 experienced employees in the semiconductor industry with functions at higher management or leading specialist level. We examined the perceived collaboration in comparison with other projects and partners. We evaluated the quality of the product and speed of market introduction along with the most important objective of the project ex-ante, and we asked whether the objective was achieved at the end of the project according to the respondent. While the sample size was limited, the data provides unique insights. Chapter 3 is based on the analysis of 335 finished (applied) research projects done within the Smart Electronics division of Imec over a period of ten years, from 2004-2014. Imec is an independent non-profit research center and one of the top three research centers worldwide in the area of semiconductors. Internal project administration is completed with external public information amongst others on patents as a proxy to determine whether the firm had prior knowledge on the subject and whether the firm used the external knowledge to continue working on the subject after the end of the project. Assuming that Imec treats all its partners more or less equally, this dataset is unique in that it provides information on the innovation performance of an R&D partnership as the focal firm changes, although the R&D partner is the same for all projects. This allows us to identity the intrinsic, rather negative, bias towards external knowledge that people and organizations possess, but also to identify several best practices that are built in the organizational culture and processes that have a high absorptive capacity and tolerance in dealing with external technology and know-how. Together, they give these organizations a clear enduring advantage in benefiting from external R&D collaboration.

## Methodologies

Throughout this dissertation, quantitative research methods were used to validate hypotheses. Although case-based studies on willingness to collaborate have led to many interesting results (Williams & Lee, 2009), the results are difficult to extrapolate, especially when, as in this thesis, the objective is to couple organizational competencies and innovation strategy it to innovation performance. Many aspects influence the performance on an individual basis; hence, it is difficult to single out a few. It is a limitation of this thesis that the number of project specific variables and unobserved variables that could be taken into account is limited as the number of observations is limiting the statistical power. The advantage of working with a larger dataset is that the effect of a few variables on the willingness to collaborate and innovation performance can be extracted much better, but this data is almost impossible to retrieve at the project level. We have given priority to the uniqueness of having data at the project level, even though the number of observations is limited. For this thesis, two different datasets were used. For Chapters 2 and 4, an online questionnaire was developed, and we sent an e-mail to 7841 addresses available in the International Technology Forum database, a yearly event, which Imec organizes in Europe, Japan, Korea, Taiwan, and the US. These events are open to non-partners as well as Imec partners in the semiconductor industry, and they are usually well visited by representatives of almost all significant semiconductor companies. Social media like LinkedIn and community websites have been used to address the community and increase the response rate. Responses were requested from semiconductor industry professionals that are senior and hold positions involving decision power. We collected data from June 19 until July 23 in 2013 and observed 235 responses, of which 111 are complete. About 50% of respondents discontinued after answering a few questions. The fact that most of the other respondents stopped answering the questionnaire quite quickly, together with a high level of experience of the people who did complete the questionnaire, gives us confidence that the right people have answered the questionnaire and that people who lacked expertise decided that the questionnaire was not for them and dropped out. Chapter 2 reports a multinomial logit model that was used to test how knowledge distance, R&D prime objective (highest product performance, shortest time to market, lowest overall cost, build-up of internal competencies, and lack of internal resources), and knowledge use strategy (complementary, replication, recombination) relate with the type of MIP as perceived by the focal firm (customer, supplier or internal). In Chapter 4, only projects in which new technology plays a role (as a minimum new to the company) were considered. This led to a sample size of 111, which, although a very significant sample size at a project level, required practical compromises on the number of variables and categories that could still be used to retain mathematical validity of the statistical models. A structural equation model (SEM) was used to relate knowledge distance, absorptive capacity, partner selection (research institute, customer, suppliers, universities, or other), the outcome of the R&D project, and new product development performance.

For Chapter 3, the database of 335 finished (applied) research & development projects contains information about the projects' start and end-dates, the responsible business, program and technical Imec officers, and the patent categories in which Imec filed patents for this research field. This data is accompanied by factual data collected from the responsible business and technical officers as well as their evaluation of the success of each project. The data on the utilization of the project results by the company are also included. Additional data was collected via individual interviews and questionnaires with 10 individuals from Business and Program management. We extended the database with patent (application) data from three years prior to the project start to three years after the project end and added shared patent (applications) information. As some of the projects did not have the responsible business & technical officer still working for Imec and we could only correlate projects that were finalized long enough to know the uptake of results after the end of the project, the number of complete data here is also limited.

## Intended contributions

Chapter 2, *Customer is king, but when to bow to a supplier?,* considers how the organizational competencies and innovation strategy of the focal firm, including the perceived knowledge distance, the external knowledge usage strategy, and the R&D prime objective, relate with who is perceived as the MIP by the focal firm. As the product specification forms the basis for the outcome of any NPD process, this study fills a gap in the current literature by explicitly defining the MIP as the partner who has the ability to dominate (parts of) the product specification in an NPD project when there is disagreement between partners. We proposed a partner selection model, which includes suppliers, customers, and internal R&D. We theorized the conditions under which a supplier or customer becomes more important than other units of the focal firm, in terms of their ability to control the product specification and timeline. Our framework draws on RDT to explain when external partners might get the upper hand in terms of negotiation power, expanded with BDT for the rule-based decision-making in times of great uncertainty.

Chapter 3, *Close collaboration matters: Relating organizational competencies with external knowledge transfer and use*, examines the relationship between organizational competencies and innovation performance of companies when collaborating with an external R&D organization. It starts with a resource-based view (RBV) of the organization, which is then complemented with aspects of BDT to explain how not-invented-here practices can hinder effective external knowledge transfer, especially for teams that already have prior knowledge in the area of collaboration. This study contributes to the literature by introducing a model of innovative project decisions that also explains unexpected (negative) results of previous studies on open innovation performance. We do this by modeling component and architectural competencies as separate constructs and validating an interaction effect between them. Using quantitative methods, this study also shows how specific drivers of component and architectural competencies relate with the R&D performance of a company working with an external partner. This had been described mostly in a qualitative manner in the literature. Besides academic contributions, this study also delivers recommendations for practicing managers on how to reduce the negative bias towards external knowledge based on the organization competencies that the firms and their R&D team(s) have prior to the start of a new collaborative R&D project.

Chapter 4, *Fill up the knowledge gap or build a bridge: knowledge distance and absorptive capacity,* focuses on how absorptive capacity and knowledge distance relate with NPD performance. The literature nowadays largely assumes that internal technical competencies and absorptive capacity are complementary skills, both needed to a similar extent to ensure adequate partner selection as well as the best new product development (NPD) performance. This paper theorizes that these aspects might be influencing NPD performance in a very different manner. We add to the open innovation literature by examining why absorptive capacity is in fact largely independent of internal technical competencies with respect to NPD performance. We found that the selection of collaboration partners depends on the perceived knowledge distance that the R&D team needs to confront rather than its absorptive capacity. On the other hand, absorptive capacity is positively associated with NPD performance, independent of knowledge distance. This more exploratory Chapter therefore combines the findings in Chapter 2 and Chapter 3 by combining RBV and RDT. We theorize that for critical, trusted partners, the knowledge gap is not seen as the gap with the internal component competencies alone, but as the gap between the internal component competencies and the external component competencies of the critical partners, provided the absorptive capacity of the focal firm is sufficient to use and integrate these external results.

Overall, this dissertation advances our understanding of how organizational competencies and innovation strategy can influence partner selection and R&D performance at the project level. This dissertation aims to explicate several key concepts of competence and collaborative innovation. It also considers practical innovation issues in a real-life (open) R&D environment. It gives guidelines for managers to spend more of their attention to the architectural competencies of their individuals, team(s), and organization, just as they nowadays spend efforts to increase the component competencies of their individuals, team(s), and organization. The dissertation warrants further research to confirm the general applicability of the partner selection model in settings other than semiconductor industry and to create more detailed, but practically usable, scales of component and architectural competencies of an R&D team. Last, this thesis shows that the R&D prime objective chosen ex-ante as the main driver of an R&D project is of great importance for the later decisions in partner selection and way of collaboration. An R&D project is not done in isolation, but part of a larger pool of R&D projects and in most companies a stage-gated innovation process. As such, it also warrants future scholars to investigate further the decision process & ex-ante decisions taken prior to starting a new R&D project.

# Chapter 2

# Customer is King, but when to bow to a supplier?: Explaining the most important partner in product development


### Abstract

Most complex new product development (NPD) projects are not done solely by the internal research and development (R&D) team(s) of a single firm. Usually, external R&D partners are involved as well. One of those partners is the most important partner (MIP) in terms of its influence on product specification. The product specification is the foundation of the product development and as such, it is crucial for the outcome and success of NPD. Yet, very little research is done on the MIP in general and very little is known about how the MIP in NPD is selected. A common expectation is that an involved customer is the MIP, being the paymaster, but this is not always true. In this study, we used a multinomial logit model on 107 finished NPD projects to examine how knowledge distance, external knowledge usage, and R&D prime objective of a firm relate with who becomes the MIP (i.e., whether the MIP is a supplier, customer, or internal) in NPD. This paper contributes to the literature with the concept of the MIP for product specification. It provides initial validation of how knowledge distance, external knowledge usage, and the R&D prime objective of the focal firm relate with the MIP outcome. The explication of MIP adds to the Resource Dependence Theory a clarification on which R&D partner gains importance, and with that power and control, based on the focal firm's prior organizational competencies and R&D prime objective.



*Keywords*: R&D partnering, new product development, partnership selection, knowledge distance, RDT, recombination, customer, supplier

## Introduction

Most complex innovation projects are not conducted by a firm on its own. Firms often cannot undertake new product development (NPD) initiatives alone, especially when utilizing new technology. In a vast majority of cases, research and development (R&D) partners are involved (Chesbrough, 2006; Roberts, 2001). In most cases, more than one partner is engaged. The extensive literature on R&D partnerships (Kesteloot & Veugelers, 1995; Lhuillery & Pfister, 2009; Schmiedeberg, 2008) has dealt with many issues, including partner selection. NPD projects in semiconductor industry are of such complexity that they are usually undertaken by one focal firm with at least one R&D partner. The decision to find R&D partners is linked to the firm's prior decision to carry out its own NPD activity (Piga & Poyago-Theotoky, 2004). The focal firm usually decides on the R&D partners that become involved, with an exception of a customer who might come to the focal firm with the intention to have an NPD activity executed explicitly on their request by this focal firm. Even in that case, though, it is an explicit business decision of the focal firm to start an NPD activity prior to further selection of partners. Among the R&D partners that become engaged, the partner that is considered to be the most important partner by the focal firm has great influence and will dominate (parts of) the product specification when the R&D partners are in disagreement, such as about the required (in case of a customer) or maximal obtainable (in case of a supplier) functionality of the product. There is a decent amount of literature describing the R&D partner selection process in different market, domain and technology circumstances (Beckman, Haunschild, & Phillips, 2004; Classen, Van Gils, Bammens, & Carree, 2012; Dekker, 2008; Diestre & Rajagopalan, 2012; Emden, Calantone, & Droge, 2006; Reuer & Devarakonda, 2017).

However, little is known about which R&D partner will be seen as the critical partner and as such will get the negotiation power to dominate the product specification, especially at times when multiple R&D partners involved are in disagreement. This is an evident gap in the current research, as the product specification is the anchor of the new product development outcome and affects its success or failure. To address this gap, we investigate who is the most important partner (MIP), or lead partner, from the perspective of the focal firm. We take the perspective of the focal firm, the firm overall responsible of the product delivery, as they are in the lead for the selection of the R&D partners. The MIP is the partner that we expect to be leading in deciding on specifics within the product specification, when there is no agreement between partners on certain requirements. This MIP can be Internal, i.e. a unit of the focal firm for example the internal product management or R&D team as the focal firm usually owns the product requirement specification. Alternatively, the MIP can be a lead customer or a critical supplier. The notion of MIP can be related with resource dependency theory (RDT). RDT discusses how organizations form coalitions and pool with external resources to decrease uncertainty and manage interdependence (Pfeffer & Salancik, 1978). Central to this theory is the concept of power, which is the control over vital resources (Ulrich & Barney, 1984). Organizations attempt to reduce the other's power over them, and increase their own power over others. When a focal firm sees a customer or supplier as MIP instead of themselves, they believe that the resources of that partner are so critical to their product success that they are giving up part of their negotiation power in order to have certain access to these external resources. Knowing who the MIP is, is very important as it indicates who, in case of disagreement, controls the product specification which is in its turn highly related to the future product success but also to the innovation progress of the focal firm. We expect to identify three important predictors of who becomes the MIP. First, knowledge distance as seen from the focal firm, which describes the distribution in terms of expertise, will determine what kind of partner is seen as MIP taking charge of the specification in times of disagreement. Second, such partner also reflects the firm's business priorities, which are reflected in the R&D prime objective for the NPD project at hand. Third, the MIP outcome depends on what the focal firm wants to do with any external knowledge introduced within the project, that is, does the focal firm use it 'as is,' adapt it to fit with its internally developed knowledge, or truly co-develop with an external R&D partner?

Combining these three aspects together, in this paper we investigate how knowledge distance, external knowledge usage, and R&D prime objective of the focal firm are related with who is seen by the focal firm as the most important partner (MIP) in new product development (NPD). We developed a model to examine the circumstances under which a supplier or a lead customer becomes the MIP rather than the focal firm itself. We assume that the information needed to decide on the partnership is not readily available but needs to be searched, which requires valuable resources, such as time, money, and attention. This all takes time and effort and combined with market and technology uncertainty, the focal firm will start to select the partner mainly rule based according to behavioral decision theory (BDT) (Gomes-Casseres, 1997). Thus, we modeled the partnership selection process based on the BDT. As a base, we assume that a unit of the focal firm itself (internal R&D and/or product team) is in the lead; hence, the focal firm itself is MIP. When a customer is involved, we assume that the customer has a good chance of taking over being the MIP as they are the paymaster. But not when focus is on lowest cost of the overall product. On the contrary, when highest product performance is the prime R&D objective, and there is an external technology critical for product development, a supplier will more likely become the MIP.

This study fills a gap by explicitly defining the MIP as seen by the focal firm. This adds to Resource dependence theory (RDT) (Pfeffer & Salancik, 1978) RDT emphasizes and takes on an external perspective and discusses how organizations form coalitions and pool with external resources to decrease uncertainty and manage interdependence (Pfeffer & Salancik, 1978). They build closer relationships to reduce resource dependence and increase power (Atuahene-Gima & Li, 2004), which is exactly the behavior followed by a focal firm when they create a stronger interfirm coalition with a customer or supplier when confronted with larger external market- customer- or knowledge dependency and uncertainty. This study contributes from the perspective of the focal firm that suppliers investing in their innovativeness indeed manage to shift the power balance in their favor in certain cases. It is important to know who the focal firms sees as MIP, as this is the partner who, in case of controversy amongst partners about certain requirements, determines what will be in the product specification, and the product specification is the base of product success or failure. Ozcan and Eisenhardt (2009) show that it can be unique and advantageous for multiple types of firms to be highly interdependent as is the case in the semiconductor industry. Gulati and Sytch (2007) differentiate between two dimensions of interdependence – dependence asymmetry and joint dependence. They find that joint dependence can be a means of reducing uncertainty and enhance firm’s performance. As such, we also see the definition of MIP as an opportunity for future research on interorganizational relationships combining RDT with RBV. This can be helpful to consider the dynamic nature of these dependencies and power as well as the multiplexity of interdependency which is still a largely open research areas as suggested by (Hillman et al., 2009).

The second contribution of this paper is that it offers a model to explain how knowledge distance, external knowledge use, and the R&D prime objective of the focal firm relate with who will be seen as the MIP by this focal firm. We propose and validate some ways in which a partner can become the MIP. As far as we are aware, this has not been explained in the literature thus far. RDT stresses that the environment and other external forces can determine how firms organize themselves to compete in the marketplace (Pfeffer & Salancik, 1978).The explication of MIP adds to this theory by clarifying which R&D partner gains importance, and with that power and control, based on the focal firm’s prior organizational competencies and the R&D prime objective.

Throughout the paper, we use the assumptions of bounded rationality, namely satisficing instead of maximizing and rule-based behavior of the decision makers at the focal firm when there is uncertainty (Cyert & March, 1992).

## Literature and concepts

In this section, we give a brief overview of the literature and explain the concepts used in our model, starting with the concept of the MIP, followed by the R&D prime objective, Knowledge Distance, and Recombination, as a specific form of external knowledge usage (EKU).

### MIP in NPD: lead customer, focal firm internal, and critical supplier

Product development usually involves internal R&D of the focal firm. The role of internal R&D can differ greatly, from a very small contribution to defining and developing every aspect of the product in-house. De facto, we define the focal firm as the MIP when there are no external R&D partners who dominate the product specification. What happens when new product development (NPD) is done with external partners is a completely different issue that is the object of the study in this paper. The external R&D partners are usually defined from the perspective of the focal firm, i.e., they are defined as customers, suppliers, universities (Leiponen & Helfat, 2010), etc. For product specification, universities with their long-term research objectives and limited knowledge of product development are not likely to be dominant. Hence, we excluded them from our MIP selection, and we retained focal firm internal, (lead) customer, and (critical) supplier as options for the MIP selection. In this study, we examine R&D projects where in the end a product is brought to the market by one focal firm. We exclude the special case in which a product is brought to the market by more than one firm as part of a horizontal partnership. In this case, the decision mechanisms at hand are expected to differ significantly.

Noordhoff et al. (2011) showed that greater customer-relation specific investments in a focal firm are associated with more positive innovation relationship. Greater investments reduce customer opportunism and increase the ability to offer valuable insights into the innovation process. Therefore, it is expected that when a customer is involved (at least partly) as a paymaster, this customer will automatically become the MIP.  found that in the semiconductors process equipment and electronic manufacturing sub-equipment, 67% of all new product innovations came from a direct customer request (21%) or a close collaboration between the customer and focal firm. However, the customer is not always the MIP. Internal teams or a supplier as the MIP instead of a customer depends on a) the presence and contribution of the customer in terms of cash and market knowledge, b) the focal firm's decision criteria for the new knowledge needed for the specific NPD project, c) the focal firm's perception of the knowledge distance to the new technology, and d) internal capabilities of the focal firm to integrate external knowledge.

Traditionally, it was thought that suppliers would never become MIP, but the analysis of amongst others the Japanese automotive industry (Gryna & Juran, 2001) has shown that early and complete embedding of suppliers in the NPD chain can actually lead to both high asset specificity and low transaction cost. Therefore, in the last two decades, early involvement of these specific suppliers, called critical suppliers, and alignment of their R&D roadmaps have become the norm in the high-tech industry. Suppliers will be seen as the MIP in NPD only when they are a key technology contributor involved in the earlier stages of the NPD process, rather than when they are a mere implementer for the high-volume product development or testing.

**The R&D prime objective: four different priorities**

The focal firm will try to optimize its product profits as well as its R&D resource usage. There is always a trade-off to be made, and the focal firm will use its R&D prime objective to evaluate all NPD choices. This is no different from evaluating whether to integrate new knowledge in NPD and how. The decision to engage in R&D partnership is linked to the firm's prior choice to carry out its own R&D (Piga & Poyago-Theotoky, 2004). Hence, for all new technology introduced in the NPD trajectory, the focal firm will decide to develop or acquire the new technology based in large part on its R&D prime objective for the R&D project about to start. Porter three generic strategies for sustainable competition: cost, differentiation, and timing (focus) (Porter, Porter, E, & Texts, 1985). In practice, this leads to an R&D roadmap always being a trade-off between cost, product features/quality and time to market. There is a fourth prime R&D objective when the decision has been taken that the internal R&D team should build up more of a certain competence, in which case an R&D project can be started with as prime objective to build up internal competencies for the longer term. The R&D objectives in principle are a trade-off and while officially this means they are weighted, every project will have one objective that is seen as prime R&D objective for this project, and this will influence the decisions taken in terms of partnership. Therefore, the four R&D prime objectives we distinguish for the R&D project at hand are:

**Priority 1: Cost optimization**

Cost is the clearest cut case, i.e., the focal company strives to become the low-cost leader in a certain market or segment. Hence, *overall product cost optimization* is a clear evaluation criterion. When the company's new technology is introduced in the NPD, the decision to acquire or develop it in-house is based on overall product cost optimization.

**Priority 2: Superior product quality**

Differentiation is about selecting numerous aspects that are highly valued by the market and delivering superior performance on those aspects, which increases the price of a new product. In NPD, this translates to superior product quality. Product quality has been defined as the perceived superiority or excellence of a product as compared with competing alternatives in the marketplace (Collinson & Liu, 2017). However, because this a general definition, it is important to understand specific dimensions along which the superiority of a product should be evaluated. These dimensions differ depending on the market and include aspects like aesthetics, performance, product lifetime, and workmanship (Cook & Brown, 1999). For NPD in the high-tech industry, performance is by far the most important criterion defining product quality, and little attention is paid to the other dimensions. Hence, for the purpose of this study, we considered the *Highest product performance* as a decision criterion for evaluating new technology rather than the more general product quality definition.

Besides cost and product performance, two NPD variables that always need to be traded-off against each other are time to market and building up competence for the future.

**Priority 3: Time to market**

*Time to market (TTM)* is valuable in fast-moving industries with the first mover's advantage where products soon become obsolete or in high volume low-cost industries, where being a fast follower can be a strategy. The electronics industry, including computers and mobile phones, as well as the semiconductor industry are examples where the shortest TTM can be important. In general, it is believed that the shortest TTM leads to compromises in product performance, as shortcuts are taken in the development process to meet the TTM deadline (Chesbrough & Garman, 2009).

**Priority 4: Build-up of internal competencies**

Beside time pressure, the introduction of any new technology in NPD increases technical risk (Cockburn & Henderson, 1998) while a shortage of capable people introduces further development risks. Therefore, an additional R&D prime objective is to build internal competencies, which reduce later development risks. Avoiding new technology in NPD is not an option. If core competencies from companies are not supplemented with new knowledge from outside of the company, the firm will eventually find itself unable to develop innovative and attractive products (Grant & Baden-Fuller, 2004). When the new technology is needed for the future R&D roadmap of the focal firm but the risk in NPD is still seen as high, the product development team will often choose to do a feasibility study or create a prototype before moving into mass production development. This means that bringing in new knowledge to the focal firm, i.e., *building up competence for the future*, can also be an important decision criterion to collaborate on new knowledge/technology.

There can also be a very practical consideration, most that there were simply no internal resources available and hence the R&D work has to be done by a partner. This can be seen as a constraint to the above four prime R&D objectives: No internal resources available. . In our study, we have found this as a decision criterion only once and hence we have placed this in the category “other R&D prime objectives”.

We expect the R&D prime objective to influence the MIP selection, as different types of partners will optimize different criteria. Depending on what R&D prime objective has priority in the NPD project at hand, diverse partners, e.g., customer, supplier and internal R&D will be preferred. To summarize, the R&D objective options include:

1) The lowest overall cost of the product (including repeat usage cost),
2) The highest product performance compared to competitors’ products in or entering the market,
3) The shortest time to market (first mover advantage or fast follower strategy),
4) The build-up of internal competencies for the future (the knowledge is expected to be needed for future product generations and the internal R&D team needs to become more competent in this area).

It is important to realize that these criteria are trade-offs that often affect each other; hence, weights for the different criteria differ depending on the firm’s global and product strategy. Usually, as a part of the product strategy or the immediate resource situation at hand, one criterion dominates the decision matrix (Rechtin & Maier, 1997). This *most important new technology decision criterion* was used in *our study as representation of the R&D prime objective*. Once a firm has decided to acquire knowledge as part of an NPD process, the R&D prime objective is used to evaluate the options to acquire the new technology.

**Knowledge distance**

An important concept, which is of importance in partnership selection, is the external knowledge distance (KD), or the extent to which two organizations, in this case, the internal

R&D team and the external partner, are technologically related. Knowledge distance is usually defined as a function of the extent to which two knowledge entities are technologically related (Makri, Hitt, & Lane, 2010; Rosenkopf & Nerkar, 2001), but *as we look into a knowledge sourcing context, we define knowledge distance (KD) as the affinity of the focal firm's knowledge-base with the new technology that it seeks to obtain (Peeters, 2013). A higher knowledge distance suggests a lower relatedness.* KD also influences the ease with which new knowledge is integrated with prior knowledge. At least a fraction of new knowledge needs to be related to prior knowledge (Cooper, 1994). Before starting the search for partners, the focal firm assesses the knowledge distance between its internal competencies and the new technology needed in the project. KD is closely linked to search, as one of the dimensions along which search can be targeted (Rosenkopf & Nerkar, 2001). The KD between the focal firm's technical competencies and the new technology has been found to influence the likelihood of finding the right potential knowledge providers in the market and the match of the external technology (Levinthal & March, 1993; March, 1991). We assumed that the product management team, together with the internal R&D team, assesses the perceived KD between the own internal R&D unit and the new technology needed in NPD. When the perceived knowledge distance is high, the internal R&D unit is more likely to look for R&D partners who can bridge the gap. When the knowledge distance is low, the internal R&D unit might be able to bridge the gap easier. Therefore, we assumed that the KD will affect the choice of partners and introduced KD as an independent variable in our model.

**External knowledge use: recombination**

Creating new knowledge involves combining internal knowledge and external knowledge in a novel fashion (Bapuji & Crossan, 2004; Bierly & Chakrabarti, 1996; Vera & Crossan, 2004). When looking at the integration aspect, one can distinguish three main categories of External and Internal knowledge integration. *External knowledge use* can be defined as:

- Complementary i.e., the knowledge developed is mainly internal. It might be complemented by external knowledge, which then has to fit in with the internal knowledge components with little or no adaptation to them;
- Replication, defined as using external knowledge in the state in which it was acquired with little or no adaptation (Szulanski et al., 2004), and

Recombination, defined as substantial performance-enhancing modifications to both existing internal knowledge components as well as external knowledge components (Gruber et al., 2012). In this study, we have operationalized recombination by looking into the case where co-creation took place; in this case, recombination is very explicit. Many studies have emphasized that firms must be able to absorb and use the knowledge effectively if they are to benefit from external knowledge (Bönte, 2005; Griffith & Harvey, 2004). For external knowledge use, mastering recombination is the highest form of innovativeness; hence, it is most effective in integrating the external knowledge together with the internally generated knowledge. The capability to recombine is of great importance for companies to be able to benefit from external knowledge; however, this does not mean that recombination is needed or preferred in all cases. Recombination also introduces additional effort and risks, and hence should only be done when the expected gain is large enough. In this study, we consider when co-creation was applied in an R&D project and it is likely that an intensive form of recombination (for whatever reason) influences the selection and importance of R&D partners.

## Hypotheses

Product development usually involves internal R&D. The role of internal R&D can differ greatly, ranging from a very small contribution to defining and developing every aspect of the product in-house. In the absence of external R&D partners, the focal firm itself, i.e. internal R&D and/or product team will be the MIP, as they dominate the product specification. When new product development (NPD) is done with external partners, one of the external partners could become MIP instead. As a baseline in our theory development, we argue that a customer, when involved, will usually become the MIP, as that firm is the paymaster of the focal firm H1. In case of a higher knowledge distance viewed from the focal firm, customers and suppliers have a better chance of becoming most important partner, as the focal firm might lack knowledge that is indispensable for the product specification (H2). When a supplier or customer replace internal R&D efforts in a certain domain, the R&D organization still needs competencies to be able to absorb and exploit the external knowledge, preferably by means of recombination. When there is no need to recombine external technology, it is less likely that a customer or supplier will become MIP (H3). In case of lowest overall cost being the R&D prime objective, many customers are often addressed so no individual customer dominates product specification. In these cases, the focal firm itself will remain more often MIP (H4) even when customers are involved. However, in some cases, especially when focusing on the highest product performance as R&D prime objective, the NPD requires unique contributions, which cannot be delivered by the customer or by internal R&D, such as new technology that fulfills a major part of the product requirements. In this case, it is likely that a supplier takes over the role of MIP (H5). Only a supplier that brings something special to the table in terms of critical technology, equipment, or infrastructure can be seen as a critical supplier and only a critical supplier can, in certain conditions, become MIP over a customer and the focal firm itself. In this case, the knowledge distance is expected to be higher (H2). If there were available alternatives, i.e., other suppliers or internal R&D that can take over the supplier's role without too much additional cost, performance, or time loss, the negotiation trade-offs would be such that the focal firm or customer would keep control of the product specification and simply exchange the supplier when the supplier becomes too demanding. Figure 4 provides an overview of the research model, which is further developed in detail in the following paragraphs.

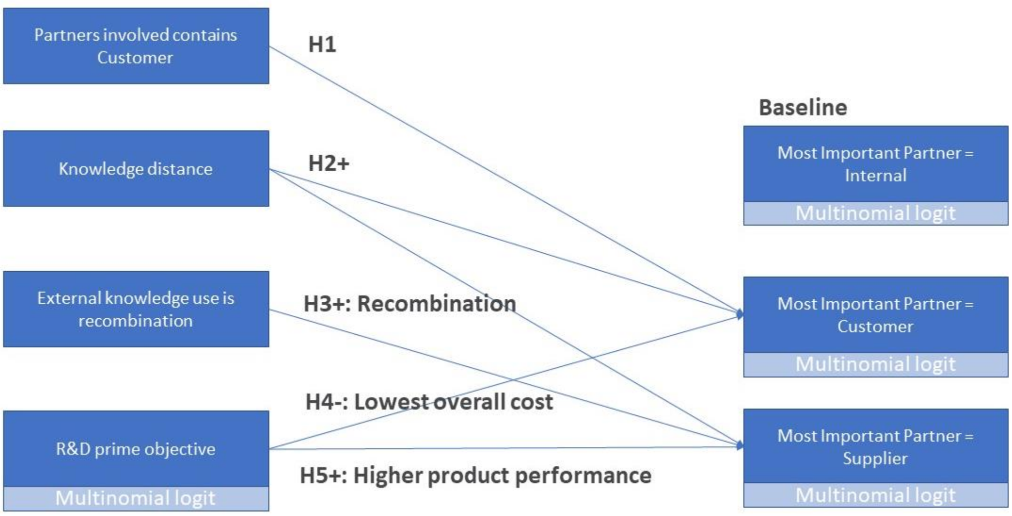


*Figure 4. MIP model*

### Customer as MIP

The importance of lead customers has long been recognized to help define the needed innovations and, therefore, reduce the risk associated with their market introduction (Kline & Rosenberg, 1986; Roy Rothwell, 1977; R. Rothwell & Gardiner, 1985; Von Hippel, 1978). (Shaw, 1994) summarized the advantages of working closely with customers (or users), which include: providing complementary knowledge, possibly including the users' technical know-how; helping to find the right balance between performance and price. This can also be important for standard setting; providing an understanding of user behavior that can be important for refining innovation; and enhancing the chances that other firms within the same user community will accept and adopt the innovation.

Working closely with a customer is likely to be important if the firm is respected within its community and if the focal firm is relatively unknown. It is also likely to be particularly important when the innovation is more radical rather than minor. Regardless of any R&D prime objective or prior knowledge, customers are also the paymaster of the focal firm. In the high-tech industry, the two extremes in this respect are that one customer is the full paymaster, i.e., the product is developed especially for this customer, while the other extreme is that a product is cost-optimized rather than customized to be sold to many different customers. In this latter case, the customer, by buying the final product, is only a paymaster in an indirect manner. In the first case, the product is developed specifically for one customer, and the customer pays for this development directly. While we did not measure this distinction explicitly, our eventual prediction is expected to hold for both extremes and the cases in between. In the first case, when only one or a few customers buy a specific product, a customer dominates in the negotiation process, the customer can almost enforce the focal firm's collaboration. The customer's influence in the decision process around the product specification will be high, both from the aspect of being a paymaster as well as from the aspect of being able to provide collaboration advantages, as Shaw (1994) described. In the case of pure cost optimization, an individual customer's request for a product requirement or their user input might not be relevant for the other wide range of customers targeted by the focal firm. In this situation, the decision power of the customer will be significantly smaller, as during negotiations, only a (small) part of all the paymasters is present. Additionally, they will usually also have less to contribute in terms of the four collaboration advantages, as described by (Shaw, 1994). Still, if they do not contribute significantly, either for one or more of the four reasons mentioned by Shaw or as paymaster, it is fair to assume that the focal firm will not involve them in the R&D project. If the customer is not a major paymaster, the focal firm dominates the process and decided whether the customer will be involved in the R&D project. The focal firm will involve a customer who is not a major paymaster only if this firm contributes significantly. Otherwise, from the focal firm's perspective, such customer is just hindering project development. Hence, our first hypothesis is that when customers are involved in an R&D project, the focal firm will view one of them as the MIP. Hence, this leads to Hypothesis 1 of our model.

*Hypothesis 1: When one or more customers are involved in an NPD project, one of them is likely to be the MIP.*

More surprisingly in certain cases, a customer is involved, but not acting as MIP. We will now further hypothesize under which circumstances this will be the case.

**Knowledge distance**

The internal R&D team assesses the KD between the own internal R&D unit and the new technology needed in NPD. When KD is high, the product team and the internal R&D team will be more likely to look for R&D partners that can bridge the gap. These partners can be customers (as per baseline) or suppliers (as we discuss below). Conversely, when knowledge distance is low, neither the customer's input (in terms of end-market expertise) nor any supplier's specific (technical) expertise is indispensable. Furthermore, the project is less likely to require high investments that a customer would (partly) provide. Accordingly, we expected that the focal firm's own internal R&D team is more likely to be the MIP when knowledge distance is low and that a higher knowledge distance favors a customer or supplier to become MIP:

*Hypothesis 2: The higher the knowledge distance, the more likely that a customer or supplier will be MIP.*

Conversely, at high knowledge distance, the need for a partner that bridges the technical gap becomes compelling, which requires looking upstream in the value chain. The value chain in modern economies is characterized by interfirm specialization, where individual firms engage in a narrow range of activities to achieve a productivity gain. These narrow range of activities are embedded in a complex chain of input-output-relations with other firms (Gryna & Juran, 2001). These productivity gains come with a downside: transaction costs for fear of opportunism or relation-specific investments. The traditional thinking is that higher asset specificity leads to higher transaction costs, but analysis of amongst others the Japanese automotive industry has shown that this is not necessarily true and that early and complete embedding of suppliers in the NPD chain can actually lead to high asset specificity along with low transaction cost (Gryna & Juran, 2001). A supplier that delivers critical technology, equipment, or infrastructure is hence expected to be fully involved early in the process of (co-)defining product specifications as true co-developers. In this situation of co-development, a critical supplier could become MIP when the product specification is largely dependent on the product specification of the critical technology that the supplier delivers. This critical technology should not be easily replaceable, not even after a few years. This means that the supplier's critical technology, equipment, or infrastructure is unique and the knowledge distance with the internal R&D team is high, otherwise the focal firm could easily take over in time. It is important to realize that the internal R&D team still needs to have the capacity to use the results of the critical supplier. In this case, this critical supplier rather than the focal firm will be MIP. However, it is unclear what happens if a customer is involved. Since customers are naturally seen as MIPs because they are paymasters, we argue that for a supplier to be seen as MIP when there is a lead customer involved, the lead customer has to recognize that this particular supplier is the key to the final product's success. Besides the focal firm, the lead customer also recognizes that the critical technology that the supplier delivers is the key to the final product performance and is not easily replaceable. This means the critical technology is unique and not easily copied. Hence, the knowledge distance will be higher on average than in the case of a customer who is the MIP.

**Recombination**

Several authors (Roussel et al., 1991; Szulanski & Jensen, 2006) showed that the knowledge-use strategy influences the sourcing strategy and allows or excludes certain use of knowledge. Among the main strategies of using external knowledge, namely internal (any external knowledge used has to fit mainly the internal technology without much adaptation), replication (Szulanski et al., 2004), and recombination (Gruber et al., 2012). Recombination of knowledge within a firm when done correctly has been found to be an important source of firm innovation and competitive advantage (Grant, 1996; Grant & Baden-Fuller, 2004; Rosenkopf & Nerkar, 2001). Recombination is also the most difficult form of external technology use, as it depends on the integration of tacit knowledge, socially embedded routines, and sticky knowledge, and this is difficult to both transfer and master (de Jong & von Hippel, 2009; Mahoney & Williams, 2003; Roussel et al., 1991; Szulanski & Jensen, 2006; Von Hippel, 1978). When the focal firm does not recombine in a R&D project, either by significantly altering external technology or by co-creation with an external partner, there is a conscious or subconscious implication that the external knowledge is not critical for product success. If it were critical, the focal firm would actively look for a supplier that could help. Such a supplier that delivers critical technology or specifications is expected to be involved fully early in the process, (co-)defining product specifications as a true co-developer. Under this condition, the supplier or customer could become MIP. To be truly co-developers, the intent has to be to recombine. If there is recombination, the partner with whom the recombination is done is more likely to be MIP. Therefore, if there is recombination, the MIP is more likely to be a supplier.

*Hypothesis 3: When the external knowledge is recombined, it is more likely that a supplier is the MIP.*

**R&D prime objective**

***Lowest cost strategy***

When the R&D prime objective is to aim for the lowest cost product, there are three reasons why a customer will less likely become MIP over Internal. First, the lowest cost strategy is usually selected when a product is being developed for a large group of customers. In many cases, a special cost optimization project for an existing product is done, and customers are more often not involved in this cost-down version, let alone do they become the MIP.

Second, for a cost-optimized version, no or little new technology is needed, leading to two situations. In one case, a part that the internal R&D can optimize easily without an external MIP costs the most. The focal firm itself will remain the MIP. The other situation is that most of the cost reduction should come from reducing the cost of a component or subsystem delivered by a supplier. A lower price with a supplier can be negotiated only when there is a potential alternative, so the internal team has to be in the lead (rather than a critical supplier or customer) to be able to negotiate a cost reduction. Hence, when aiming for the lowest cost, the aim of the R&D project is for a large part to encourage the existing supplier into reducing the cost or to change a supplier and/or to redevelop with help of internal R&D. In all cases, neither the supplier nor the customer will be MIP, as the focal company (internal) will have to lead this process. Internal R&D and/or product team will lead the discussion of what the technical alternatives are for the technology that comes from a certain supplier.

Third, the lowest cost strategy is usually only applied in a market that is already developed rather than a newly developed market. In this case, the contributions of a customer, as outlined by Shaw (Shaw, 1994) are expected to be more limited; hence again, the focal firm is likely to remain MIP.

Based on the above, we proposed that a customer is less likely to become MIP when the R&D prime objective is aimed at lowest overall cost.

*Hypothesis 4: When the focal firm's R&D prime objective is aimed at lowest overall cost, a customer is less likely to be the MIP.*

***Highest product performance strategy***

Suppliers, just like customers, are a part of the vertical innovation chain. However, much literature thus far has described the use of suppliers mainly for lowest overall cost reasons ('make versus buy') or capacity reasons (Cohen & Levinthal, 1989, 1990). In this way, suppliers complement rather than replace internal R&D efforts. It is unlikely that such a supplier will be seen as MIP, as such a supplier does not deliver a critical technology. This kind of model, however, ignores the motivation for developing technological knowledge and innovation. Decisions are also influenced by strategic implications in the sense of balancing (and resolving the conflict between) short-term efficiencies against the long-term competitive position of the firm. Tidd and Trewhella (1997) contended that, overall, strategic considerations (including competence buildup and trust) rather than transaction costs (and cost-minimization) are more significant in terms of whether and how the firm accesses external technology. To build up internal competencies, the internal R&D team will still be the focal partner in NPD. However, one aspect of long-term competitive position is easily overlooked, that is, a specialized supplier can also be seen as a way to achieve higher product performance even over a long period when internal competencies, equipment, and/or infrastructure in a certain area are lower and not easily matched with the supplier's high expertise, equipment, and/or infrastructure. As long as the focal firm has sufficient competence to assimilate and integrate the external technology efficiently with its own knowledge database, the use of unique external technology from a critical supplier can lead to the highest product performance at a lower price. This has been shown for the automotive industry (Gryna & Juran, 2001) and for other high-tech industries, including semiconductor, computer industry, and biotechnology (Bierly & Chakrabarti, 1996; Diestre & Rajagopalan, 2012; Gryna & Juran, 2001; Kesteloot & Veugelers, 1995). A supplier becomes the MIP because this supplier is an integral and pivotal part of the NPD, not just cost economics. Usually, investments in the relationship will be heavy (creating trust and goodwill) and asymmetric information will be reduced (agency theory) to optimize the product performance and benefit both the focal firm and the supplier. Hence, for a supplier to become MIP, highest performance rather than internal competence build-up (internal R&D still focal partner) or cost minimization (the supplier might be present but is not a strategic partner) is the reason to have a supplier as MIP in an R&D project.

*Hypothesis 5: When the focal firm's R&D prime objective is aimed at the highest product performance, it is more likely that a supplier is the MIP.*

Figure 4. MIP model on page 31 shows the complete model depicting our hypotheses.

## Data and Method

### Data collection and characteristics

This study focused on the interrelations between knowledge distance, R&D prime objective (highest product performance, shortest time to market, lowest overall cost and build-up of internal competencies), and the use of recombination with the type of MIP in an innovation project (customer, suppliers and company internal like internal R&D and/or product team). Given the research question, a quantitative research approach was considered the most appropriate. Case-based studies on willingness to collaborate have led to many interesting results (Williams & Lee, 2009), but the results are difficult to extrapolate. At the same time, many of the constructs above cannot be reliably obtained from secondary sources. Thus, we conducted a questionnaire study.

Our questionnaire was adapted from Peeters' (2013) dissertation on absorptive capacity and knowledge use in the gaming industry, with his kind permission. Questions that were not relevant for this study were removed and additional questions were added specially to relate the use of new technology and the R&D prime objective with the R&D partners involved. For these items, we sought and used pretested questions from the literature as much as possible (Praest Knudsen & Bøtker Mortensen, 2011; Steensma & Corley, 2001). The list of questions as well as the source of the questions can be found in Appendix 1.

To get a broad and highly relevant respondent population, we addressed 7,841 persons for whom the data was available in the International Technology Forum (ITF) database. Imec, one of the top three worldwide research organizations in semiconductor technology, organizes ITF as a yearly event series in Europe, Japan, Korea, Taiwan, and the US. These events are open to non-partners as well as Imec partners in the semiconductor industry, and they are usually well visited by representatives of almost all significant semiconductor companies.

The data used for testing the multinomial logit model were gathered from persons working in the semiconductor industry. The invitation to participate e-mail was constructed according to the guidelines in (Dillman, Smyth, & Christian, 2008). Responses were requested from semiconductor industry professionals that are senior and hold positions involving decision power. We collected data from June 19 until July 23 in 2013 and observed 235 responses, of which 111 are complete. About 50% of respondents discontinued after answering a few questions. The fact that most of the other respondents stopped answering the questionnaire quite quickly, together with a high level of experience of the people who did complete the questionnaire, gives us confidence that the right people have answered the questionnaire and that people who lacked expertise decided that the questionnaire was not for them and dropped out. Eighty percent of these respondents have worked in the semiconductor industry for more than ten years and thus have seen a considerable number of projects as a frame of reference. The size of projects they have worked on varied from very small (just one person) to very large (>1000 people and a $100M budget/year). The geographical response distribution of respondents was spread reasonably worldwide, with responses from all significant semiconductor areas of the world, i.e., Japan, Taiwan, Korea, America (includes Canada), and (Northern) Europe. Our belief in the accuracy of the results is supported by several studies that have shown that surveys with lower response rates often have more accurate measurements than surveys with higher response rates (Keeter, Kennedy, Dimock, Best, & Craighill, 2006; Visser, Krosnick, Marquette, & Curtin, 1996).

The questionnaire allowed individuals to skip individual questions because of confidentiality issues and to avoid respondents rejecting the whole questionnaire. We checked for non-response bias by comparing the characteristics of the respondents' companies to those of the targeted population sample. The respondents represented 7 out of the top-10 semiconductor companies. The companies involved ranged from small startups to very large firms. Every person could only submit one response describing his/her latest finalized project. There was no overlap in project representation in the sense that more than one respondent answered about the same R&D project. No company was overrepresented in the response: one company had 6 respondents, one had 5, three companies had 3 respondents, and all other companies had 1 or 2 respondents. In the section titled "Validity of the model", as well as Appendix 2, we show that the results are robust when correcting for overrepresentation.

One potential issues with surveys is common method bias (CMB), i.e., the variations in responses are caused by the instrument rather than by the actual predispositions of the respondents. By using, as much as possible, validated questions from earlier studies as well as doing multiple test-rounds of the questionnaire to refine the new questions, we intended to limit CMB. We guaranteed the anonymity of the respondents to avoid socially acceptable (positive) answers. We asked for a finalized project to avoid the optimism bias (Sharot, 2011) when still actively working on an activity. In the results section, we report variable characteristics to validate further that CMB is not a real issue in this dataset. The questionnaire results are relevant in view of the high experience of respondents and the senior functions the respondents held, as well as the good geographical spread of respondents. (Armstrong, 1977) argued that late respondents are representative of non-respondents. We found no difference between early and late respondents in general characteristics, such as experience in the industry (p=0.76) or geographical location (p=0.70).

We highlight some important characteristics of our survey group to make the later results easier to interpret. Our data showed that in 89% of all projects, technology new to the company was used, suggesting that using new technology in product development is a daily practice in semiconductor companies. The degree of newness of technology was distributed normally over ‘new to the world (30%), new to the market (30%), and new to our company (40%).’ Because of our specific research question in this paper related to the R&D prime objective, we have omitted the responses were the respondent indicates they do not know the R&D primary objective. This reduces the number of observations from 111 to 107 projects. Figure 5 shows who participated in the R&D project.

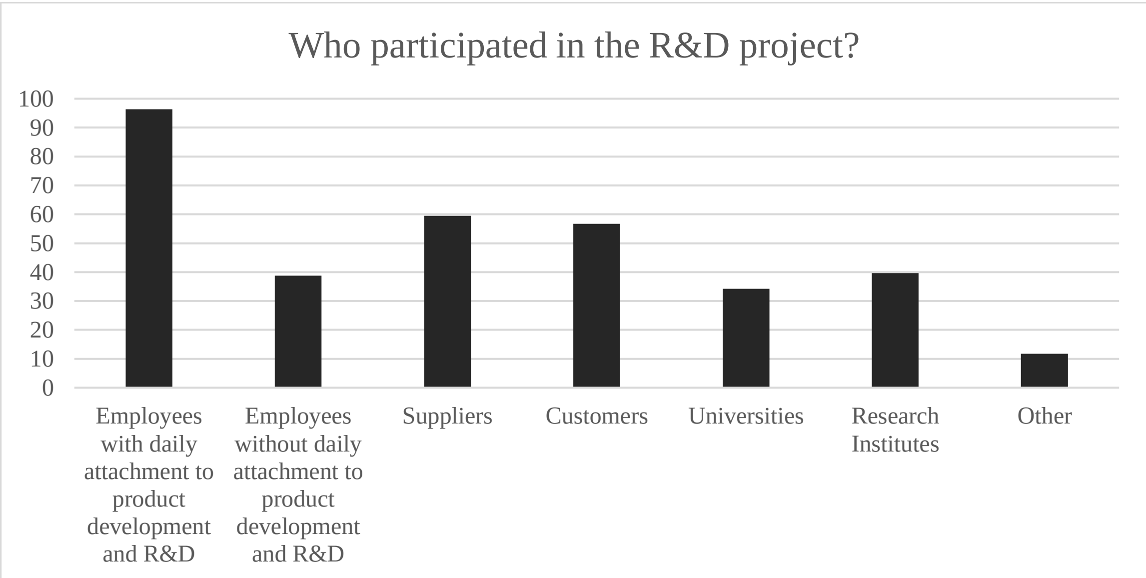


*Figure 5. Who participated in the new product development project? Percentages; N=107.*

There were a few projects were no employees with daily attachment to product development and R&D were involved. This can be the case when e.g. the project’s only aim is a one-on-one replacement of a supplier, i.e. a second source for a module or component. Figure 5 also shows that product development in the semiconductor industry almost always involves partnering with external R&D partners and in many cases with more than one external party. Customers were participating in more than half of all projects, and the same was true for suppliers. 90% of the projects had at least one external R&D partner, 63% had two or more external R&D partners, while 37% had three or more external R&D partners.

### Operationalization of variables

#### Outcome variable

*Most important partner, MIP*, was operationalized as focal firm internal, customer, supplier, research institute, university, or other. To validate hypotheses reflecting the original model used in this paper, all different categories of MIP were used. Further details can be found in Appendix 1.For control purposes, we also measured the number and types of partners involved in the project. As can be seen from the results, most R&D projects had actually multiple partners, forming a true alliance rather than a single bilateral partnership. This implies that in the vast majority of cases, identifying the MIP is a relevant question.

#### Independent variables

Three questions were used to assess the latent variable *knowledge distance* on a 7-point Likert scale ranging from 1 “Strongly disagree” to 7 “Strongly agree.” In some cases, the questions were reverse-coded, i.e., the Likert scale had to be inverted to transpose knowledge distance in a manner consistent with the other questions. In the original questionnaire, a fourth question on knowledge distance was present: “Much investment in equipment or staff would be required of our firm to independently develop this technology”. We did not take into account the answer to this question in this paper, as it relates specifically to CAPEX investments to be done in equipment or manufacturing, which is only applicable for a supplier; and even in this case, if it is based on manufacturing investments there is usually an alternative in the market. For our purpose of investigating the MIP with the idea that this partner influences the product specification most when there is disagreement, the need to do CAPEX investments is not representative. A customer can become MIP in terms of their ability to bridge knowledge distance with their end-market expertise and a supplier can become MIP in terms of their ability to bridge specific (technical) expertise. A supplier can also bridge a specific gap by having expensive equipment that is hard to copy by the focal firm; but normally, if the issue is just to overcome high investment costs for manufacturing, there is an alternative supplier in the market place and hence this does not make a supplier MIP.

*R&D prime objective* was measured by asking the participants to select all as well as the single most important decision criterion for the use of external knowledge from the following list:

1. Build-up internal competence for the future
2. Lowest overall cost
3. Highest product performance
4. Shortest time to market
5. Lack of internal resources and other (open).

More than 95% of the answers fell into the first 4 categories found in the literature; hence, the selection of criteria was reliable. Before asking the participants to identify the most important decision criterion, we asked which decision criteria played a role in the decision process. Although in most projects, there is a trade-off between multiple decision criteria, all respondents that knew which decision criteria were used to decide on external knowledge, also were able to identify the primary R&D objective. This is an indication that while the decision processes for external knowledge usage include trade-offs, firms usually have a clear strategy based on the most important R&D objective in a project.

*Recombination,* measured using the question, “Which statement applies best to your most recently finalized project?” was used as a dummy. Recombination was set to “0” when respondents answered either “mainly developed internally” or “received from a partner but made little alterations.” Recombination was set to “1” when respondents answered, “we co-created it with a partner.” The answers, “We mainly developed the new technology on publicly based available technology” was ignored hence recombination was set to “0”, as it is impossible to determine on the basis of this whether the knowledge use strategy is mainly internal, replication, or recombination. This is a topic to consider for future research. Additionally, the answer “we received the new technology from a partner but significantly altered it” was ignored in the analysis, as it was ambiguous and did not discriminate sufficiently between the complementary knowledge use strategy and the recombination strategy.

We have added a few control variables in our analysis to correct for project specific implications. Specifically, we have added a variable which indicated the *newness of the technology* that was being developed, being: “0” new to the world, “1” new to this market; “2” new to our company (but known in the world and this market). We also added an integer variable about the *number of partner types involved*, where we count the different categories of partner types, including focal firm internal, that were involved. This should correct for complexity of the organization of the project and – in a more indirect and imprecise manner – this is also expected to say something about the size of the project.

## Regression methods

As the dependent variable discriminates between three unordered outcomes (a customer as MIP, focal firm internal as MIP, or a supplier as MIP), and we also have a large unordered independent variable being R&D prime objective, we implemented a multinomial logistic regression. We first validated that MIP and R&D prime objective indeed have significant association by looking into the Chi-square test (Pearson $\chi^2_{20}=33.3$, $p<0.05$). The result can be found in Table 1. In some cases, we have fewer than the minimum of 5 expected observations per cell. The Chi-square test may not be valid in such cases (Field, 2013). We use one MIP-PO combination of customer and lowest overall cost when validating our hypothesis and hence cannot take that result to be more than a first indication.

*Table 1*
*Tabulation and chi square of most important partner versus R&D prime objective*

| **R&D prime objective** | **Build-up internal competence** | **Lowest overall Cost** | **Highest Product performance** | **Shortest time to market** | **Other** | **Total** |
|---|---|---|---|---|---|---|
| **Other** | 0 | 1 | 1 | 0 | 0 | 2 |
| **Customer** | 13 | 1 | 15 | 7 | 1 | 37 |
| **Internal** | 6 | 7 | 16 | 6 | 3 | 38 |
| **Supplier** | 1 | 0 | 13 | 2 | 1 | 17 |
| **Research Institute** | 5 | 0 | 3 | 0 | 0 | 8 |
| **University** | 2 | 0 | 2 | 0 | 1 | 5 |
| **Total** | **27** | **9** | **50** | **15** | **6** | **107** |

For the multinomial logistic regression, projects that have internal R&D and/or product team as MIP are taken as the reference group.

## Results

*Table 2*
*Descriptive Statistics, Coding MIP, and PO as Dummies*

| **VARIABLES** | Recom (0,1) | Knowledge distance (1-7) | MIP == supplier | MIP == customer | MIP == Internal | MIP == research | MIP == university | PO == Internal | PO == overall lowest | PO == highest | PO == shortest time | Newness of Technology | Parnter types involved |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Recom (0,1) | 1.000 | | | | | | | | | | | | |
| Knowledge distance (1-7) | 0.227 | 1.000 | | | | | | | | | | | |
| MIP == supplier | 0.314 | 0.120 | 1.000 | | | | | | | | | | |
| MIP == customer | -0.055 | 0.008 | -0.300 | 1.000 | | | | | | | | | |
| MIP == Internal | -0.284 | -0.195 | -0.313 | -0.520 | 1.000 | | | | | | | | |
| MIP == research institute | 0.089 | 0.1048 | -0.126 | -0.210 | -0.219 | 1.000 | | | | | | | |
| MIP == university | -0.050 | -0.021 | -0.092 | -0.154 | -0.160 | -0.065 | 1.000 | | | | | | |
| PO == Internal competence buildup | -0.046 | 0.030 | -0.176 | 0.150 | -0.140 | 0.225 | 0.085 | 1.000 | | | | | |
| PO == overall lowest cost | 0.017 | 0.112 | -0.126 | -0.140 | 0.265 | -0.088 | -0.065 | -0.164 | 1.000 | | | | |
| PO == highest product performance | -0.040 | -0.105 | 0.176 | -0.051 | -0.084 | -0.065 | -0.018 | -0.492 | -0.264 | 1.000 | | | |
| PO == shortest time to market | -0.076 | -0.004 | -0.011 | 0.134 | 0.005 | -0.113 | -0.083 | -0.210 | -0.113 | -0.338 | 1.000 | | |
| **Newness of Technology** | 0.068 | -0.081 | 0.193 | -0.015 | -0.121 | 0.130 | -0.066 | -0.057 | -0.146 | 0.175 | -0.097 | 1.000 | |
| **#Partner types involved** | 0.128 | 0.092 | 0.065 | 0.124 | -0.255 | 0.199 | -0.026 | 0.1389 | -0.053 | -0.165 | 0.091 | -0.06 | 1.000 |
| **MEAN** | 0.306 | 4.327 | 0.153 | 0.333 | 0.351 | 0.081 | 0.045 | 0.252 | 0.084 | 0.467 | 0.140 | 0.856 | 3.369 |
| **SD** | 0.463 | 1.434 | 0.362 | 0.474 | 0.480 | 0.274 | 0.208 | 0.436 | 0.279 | 0.501 | 0.349 | 0.840 | 1.446 |

Table 2 shows the descriptive statistics, specifically the correlations, means, and standard deviations (SD). Although knowledge distance theoretically ranged from 1-7, in practice, it started at 1.66, with a mean of 4.6 and standard deviation of 1.35. This is rather logical, as we have a dataset where there always is some new technology introduced; hence, zero knowledge distance is not expected. Instead, a high knowledge distance will frequently occur.

When looking at the results of the questionnaire in terms of involvement of types of R&D partners and the MIP percentages, we notice that involved customers were the most important partner in 58% of the cases, a much higher percentage than that of internal at 35% and suppliers at 29%. The results are shown in Table 3. These results are consistent with hypothesis 1 where we predict that if a customer is involved, it will likely be the most important partner compared to any other type of partner, including focal firm internal parties.

*Table 3*
*Chance of being seen as the MIP when involved in the new product development*[1]

| R&D partner | Involved | Most important | When involved, % seen as MIP |
|---|---|---|---|
| Internal focal firm | 100% | 35% | 35% |
| Suppliers | 59% | 17% | 29% |
| Customers | 57% | 33% | 58% |
| Universities | 34% | 5% | 13% |
| Research Institutes | 40% | 8% | 20% |
| Other[2] | 12% | 2% | 15% |

The results of the multinomial regression model that included knowledge distance, recombination, and R&D prime objective are summarized in Table 4, and the full results are given in Appendix 2. The small p-value from the likelihood ratio Chi-square test for the overall model, $p<0.0001$, led us to conclude that the model has explanatory power. All results were compared against the baseline, where internal is the MIP.

Table 5 shows the results of the hypothesis testing, described hereafter. Hypothesis 1 predicted that when a customer is involved, they are more likely to become the MIP than any other partner is. Support for this hypothesis was found. In hypothesis 2, we predicted that a higher knowledge distance favors the chances of a customer or supplier becoming the MIP and this was supported by our multinomial logistic regression, just as the use of recombination for the external knowledge, in this case operationalized by co-creation, increases the chances of a customer or supplier being seen as the MIP by the focal firm. This supports hypothesis 3.

A prime R&D objective of overall lowest product cost severely reduces the chances of a customer as MIP and with that, we find support for hypothesis 4. Last but not least there is strong support found that a prime R&D objective of striving for the highest product performance, increases the chances of a supplier to be seen as MIP significantly.

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[1] Universities and research institutes, though valuable in their contributions, will usually not be able to act as the MIP, as they usually contribute to the technology innovations in an early stage without fulfilling all requirements, definition of the value proposition, and time to market of the final product or service.

[2] Other category includes the competitor and consultant categories. Result is not statistically relevant.

*Table 4*
*Summary Results of Multinomial Logistic Regression, all results compared with the same result when Internal is seen as most important partner*

| | Customer is MIP | Supplier is MIP |
|---|---|---|
| Lowest overall cost | - 2.72**$ | 2.00 |
| | (1.21) | (1.21) |
| Knowledge distance (KD) | 0.37* | 0.50* |
| | (0.20) | (0.28) |
| Recombination | 1.04 | 2.48*** |
| | (0.73) | (0.84) |
| Newness of technology | 0.25 | 0.36 |
| | (0.32) | (0.43) |
| # of type of partners involved | 0.31 | 0.21 |
| | (0.21) | (0.28) |
| Constant | -2.44* | -6.01*** |
| | (1.28) | (2.02) |

*Number of obs.= 107, LR Chi(40)= 80.81; Prob.> $chi^2$= 0.0001;*
*McFadden's pseudo $R^2$ = 0.2680; R&D prime objective base category = Build-up internal competence for future.*
**Statistically significant results, with p<0.1, ** Statistically significant results with p<0.05, *** Statistically significant result with p<0.01.$ Results should be read as indicative trend, not as absolute result as field count <5.*

*Table 5*
*Overview of Hypothesis Testing*

| Hypothesis | Result |
|---|---|
| Hypothesis 1: When one or more customers are involved in an NPD project, one of them is likely to be the MIP. | Support was found. When a customer is involved, the customer has a much higher change of being the MIP (58%) versus Internal (35%) and suppliers (29%). |
| Hypothesis 2: The higher the knowledge distance, the more likely that a customer or supplier will be MIP. | Support was found. A one-unit increase in knowledge distance was associated with a 0.37 increase in the relative odds of customer and a 1.10 increase of a supplier being the MIP versus the focal firm Internal team(s). So it also shows, as expected a higher knowledge distance further favors a supplier than a customer. |
| Hypothesis 3: When the external knowledge is recombined, it is more likely that a supplier is the MIP. | Support was found. Recombination by means of co-creation is associated with a 2.48 increase of a supplier being the MIP versus the focal firm itself. |
| Hypothesis 4: When the focal firm’s R&D prime objective is aimed at lowest overall cost, a customer is less likely to be the MIP. | Support of this hypothesis is found. Note count is too low to be statistically conclusive (9 observations in total). |
| Hypothesis 5: When the focal firm’s R&D prime objective is aimed at the highest product performance, it is more likely that a supplier is the MIP. | An R&D prime objective of the highest product performance is associated with a 2.0 increase in the relative odds of a supplier being the MIP vs. the focal firm itself, but the result is not statistically valid, with a p value of 0.099. |

**Validity of the model**

We used a multinomial logistic model, which is only valid when several assumptions are met:

1) Our dependent variable, the MIP, could not be perfectly predicted from the independent variables for any case. This assumption was valid in our model, as there were many non-observed variables that could have changed the outcome. Although the independent variables do not need to be statistically independent of each other, collinearity was relatively low, as indicated by the low correlation between knowledge distance, external knowledge usage, and the R&D prime objective. The highest correlation found was 15.2%.
2) As we modeled choices, our underlying assumption was that there is an independence of irrelevant alternatives (IIA), i.e., that the selection process outcome of the supplier, customer, or focal firm internal as MIPs does not depend on the existence of other irrelevant alternatives, e.g., a university or competitor. This can be tested via the Hausman test (Myles Shaver & Flyer, 2000). For these two alternatives, it is difficult to imagine that they significantly change the selection process among a customer, internal R&D, or a supplier. Indeed, other studies have described their roles as different from those of customers, suppliers, and internal R&D (Dussauge, Garrette, & Mitchell, 2000; Laursen & Salter, 2006). We conducted the seemingly unrelated estimation Hausman test to further validate IIA and robustness. The Hausman test is a robust procedure implemented in Stata to deal with the issues described around the Hausman test by (Vera & Crossan, 2004). This test shows no IIA issues with the dataset, see Appendix 3 for full results
3) Lastly, the independent variables can be mis-specified. For the variables of MIP and R&D prime objective, this is unlikely, only two, or only a few, response options were given in the category. This means that the difference would only be a few percent. The exception is recombination, which is a binary dummy. Nevertheless, earlier literature has validated the specification and measurement of this variable.

We checked for potential bias from multiple respondents per focal firm by removing samples from the dataset randomly until only one respondent per company remained. See Appendix 3: Validity of the model, Hausman and single respondent tests for full results. Although the responses were from different respondents and about different projects, common firm factors might have influenced the results. The model remained valid, coefficients did not change direction, and the value changed only marginally so there was no overrepresentation by respondents from different companies. The coefficients remained statistically significant ($p<0.05$), except for the association between recombination and internal being the MIP. This, however, seems to be the result of the small sample size in combination with a dummy independent variable. Still, one has to conclude that applying recombination is a strong and statistically robust precondition to a supplier ever becoming the MIP, and it seems to be a negative precondition to having an internal party rather than a customer as the MIP, but this was statistically less robust.

## Discussion

This study focused on the interrelations between knowledge distance, R&D prime objective (highest product performance, shortest time to market, lowest overall cost and build-up of internal competencies), and the use of recombination with the type of MIP in an innovation project (customer, suppliers, company internal like internal R&D and/or product team. Contrary to what one could belief from cost economics that customers who are the paymasters of the focal firm will hence be seen as the MIP, we noticed that in our data, this was the case in only 59% of the cases. This study sheds light on the circumstances in which customers are not becoming the MIP but the focal firm itself remains the MIP or a key supplier becomes the MIP.

### Customer as MIP

Customers, being the paymaster, have a better chance than others to become MIP once they are involved in an R&D project. Especially when they can also help to bridge a medium knowledge gap. This can be explained from the premise of resource dependence theory (Pfeffer & Salancik, 1978), RDT, where the main premise is that firms will seek to manage dependence and reduce the resulting uncertainty by purposely structuring their exchange relationships by means of establishing formal links (Ulrich & Barney, 1984). Conceptually, the establishment of an interfirm link is viewed as dealing with the problems of uncertainty and dependence by deliberately increasing the extent of coordination with the relevant set of exchange partners (Cyert, 1963; Pfeffer & Salancik, 1978). Thus, according to RDT, one of the fundamental strategies to reduce dependence is coordination with the resource owner. (Scott, 1998) calls those activities “bridging strategies” that are implemented to secure critical resources. If one or a few customers are of great importance to the survival of a focal firm's business, the focal firm will increase the dependency by not only involving the customer early in the R&D process but also by giving them a role of vital importance in the form of being MIP. Projects where the focal firm remains the MIP tend to have a lower knowledge distance (between the focal firm and the target knowledge) and the prime R&D objective of prioritizing cost optimization. We believe that these projects will more often focus on cost optimization, being the second or later cost-optimized generation of an existing product and as such quite well understood by the internal R&D team. These projects take place in a later stage of development, when initial products are already on the market and often for a multitude of Customers. Customers will hence have less to contribute in terms of the specifications. Customers might still be included as partner, although not critical to the outcome of the project. In line with RDT this is a cyclic process, the more external resources are needed and the higher the uncertainty, the more dependency is created by forming coalitions. Once the market or technology circumstances change and the resources needed change the whole process of interdependence, uncertainty and forming coalitions to reduce uncertainty is repeating itself. So, when exploring a new market or new product on the market, customers will be much closer involved than once the market is mature and/or the product and market preferences for the product are well understood.

**Supplier as MIP**

Suppliers have every reason to want to be seen as the MIP by a focal firm to which they deliver. Following a RDT perspective, suppliers will try to be more innovative to respond to power imbalances that originate from the focal firm's control behaviors in international focal firm–supplier relationships (Bryan Jean, Sinkovics, & Kim, 2017). High technological uncertainty can also drive suppliers to be more innovative, as firms must reduce environmental uncertainty and dependence (Li & Atuahene-Gima, 2001). Especially for the latter, we found support that that the supplier is more likely to serve as MIP when the knowledge distance is higher and the collaboration is based on recombination. This is in line with the RDT perspective of a highly innovative supplier having better power balances towards their focal firms (their customers). Earlier research has already shown that more radical or complex innovations require greater information exchange and are more likely done with suppliers in the lead, because they are needed from a technology point of view and customer resistance to more radical innovations tends to be greater. This makes customers less likely to become MIP when the focus is on highest product performance. Suppliers become MIP when the knowledge distance becomes higher and the supplier is critical in terms of what they can deliver to the product. In that case, RDT predicts that the importance of this supplier, especially when they are unique in the world and hence there is no abundance of this resource, will lead the focal firm to form a coalition with this supplier and give this supplier more control. In this manner such a supplier is involved early and critically in an NPD process as they bridge a technology gap for the focal firm (as we predicted) and will be given part of the control on the product specification normally in the hands of the focal firm. These suppliers are delivering a part of the product or service so critical for the overall product performance that they have to become the MIP. We predicted that for suppliers as the MIP, the focal firm more often uses a recombination strategy. A possible explanation can be that in order to use a supplier for a critical technology within the specified product or service, focal companies understand that they have to align their roadmap, development and logistic processes to a very high degree with the supplier at hand. When doing so, they automatically move into a recombination or co-creation strategy, especially when the supplier is large (Bryan Jean et al., 2017; Li & Atuahene-Gima, 2001). Returning to the title of this Chapter, it seems that the focal firm has to bow to a supplier when it wants to achieve more radical or complex innovations that it cannot do on its own but solely with a (specialized) supplier in terms of technical know-how and/or cost. Investing in this relationship should be based on the perceived value proposition, where the added product performance delivers a clear advantage in the (future) market place. Our expectation was that the relationship between the focal firm and the supplier turns into enduring collaboration over time rather than a one-time collaboration. This can be another venue for future research.

**Theoretical implications**

The results of our study add to the literature of RDT (Cyert, 1963; Cyert & March, 1992; Pfeffer & Salancik, 1978; Scott, 1998) by offering insights into when suppliers can become the MIP rather than a replaceable partner to reduce cost. RDT describes that when the focal firm will see the external resources of the customer or the supplier as highly critical for its (future) product success, the focal firm will show relationship behavior to make sure that these resources are ensured. This can lead to the focal firm giving up part of their negotiation power for a key customer or critical supplier. When an external partner, supplier, or customer, becomes the MIP rather than the focal firm itself, this external partner becomes an integral and pivotal part of the NPD, as this supplier or customer can decide in terms of the product specification when there is disagreement on critical parts of the specification. The customer as MIP can then use its negotiation weight to adapt product specifications to their liking, while the supplier as MIP can use their negotiation weight to reduce product specifications to workable, or easier realizable specifications as far as the specification relates to technology delivered by them. A supplier who wants to become MIP and hence have more weight in the power balance with its customers, in this case the focal firm, better invests heavily in innovation (Bryan Jean et al., 2017; Ku, Wu, & Chen, 2016; Wagner & Hoegl, 2006) and in the relationship creating trust and goodwill and reducing asymmetric information (agency theory), to optimize the product performance in order to benefit both the focal firm and the supplier. It is important to build trust with the supplier in the process of reducing transaction cost over time. Although earlier studies have pleaded for such an integral view (Cyert, 1963; McIvor, 2009), the different views often contradicted each other. The perceived knowledge distance, knowledge usage and R&D prime objective of the focal firm explain what type of partner is viewed as MIP by the focal firm. This adds to the theory of outsourcing and partner selection, as the outcome of this study suggests that the competencies of the focal firm to build and retain long-term relationships with external partners becomes a critical competency when the one or more supplier(s)s or customer(s) are the critical to realize the (future) product success in the market. On the contrary, when the innovation aim is to achieve the lowest cost, suppliers are weighted against internal R&D in terms of development cost and are in general not seen as the lead partner or MIP. In this case, price negotiations with suppliers is a more critical competency than building long-term relationships with them. Therefore, it is of utmost importance to understand the intended R&D prime objective of the NPD project at hand. Thus far, while the decision factors have been described, this R&D prime objective has not been explicitly addressed in literature, hence the weighting of different decision criteria in the partner selection has been unclear.

A customer as the MIP seems to indicate a product with slightly higher knowledge distance versus the focal firm itself in the lead. However, we can see from the results that customers do not become the MIP in just any situation, even when they often are the paymaster for the focal firm. In addition, here RDT suggests that the focal firm assesses the dependency on the customer in terms of its competencies and expected (financial and knowledge) contributions. The focal firm involves the customer earlier and more interactively when the customer’s anticipated contributions are high and less when anticipated contributions are lower.

This Chapter adds to RDT theory the concept of a most important partner and shows that at least three predictors of the focal firm explain differences between the most important partner and the other partners. Specifically, we find that the R&D prime objective and prior internal technical competencies as well as the use of recombination relate with how the focal firm involves and views their R&D partners, and which type of partner is most important. We show that the decision process is based more on a complex trade-off rather than on "who pays," as is normally assumed in cost economics. While more complex, the decision process seems to remain mainly rule based and hence also fitting a BDT model of rule-based decisions in times of high uncertainty.

**Limitations and future research**

The dataset used in this study is unique, as it is derived from experienced employees with an extensive experience in their industry; hence, we can compare their latest project with previous projects. Still, the assessment was done by someone directly involved in the R&D project (though they responded after the project ended) and while the sample was unique in terms of involvement of companies from all over the world, large and small, the sample size was rather small. For that, it makes sense to redo the analysis with larger sample size, but since this will not be easy to collect, another option would be to do a more focused study based on the interviews with managers and executives.

An important limitation is that we investigate the project with the partner set as it was at the time of execution, in other words, the partners involved have agreed to the focal firm's intent to partner. We have no knowledge of how often a focal firm's intent to partner is rejected by the preferred potential partner or its partnership form altered by its behavior. The focal firm might prefer a certain partner to take the lead and become the MIP, but the intended partner might feel differently. When they behave much less competent or less in the lead than expected, most likely the focal firm will quickly not perceive them as MIP and maybe not even as R&D partner at all for a future project.

We found unexpected results in terms of knowledge distance influencing the selection of supplier as the MIP over a customer. We expected that a higher knowledge distance would increase a supplier's likelihood to become the MIP more than a customer, but in fact, these effects hardly differed from each other. This might be because a supplier may have a small knowledge distance yet possess specialized equipment or infrastructure. Thus, in this case, the supplier becomes the MIP to achieve the highest product performance. We expect that this relationship could differ when the focal firm and supplier have different firm sizes. It is also possible that knowledge distance is not shaped in a linear function as we have assumed in our current model. There is probably an optimality between a partner who is close to your own knowledge base or far away and where this optimality is, probably also depends on the firm's level of architectural competencies, specifically their absorptive capacity. Bryan Jean et al. (2017) have suggested that a too large knowledge distance is detrimental for innovativeness. We have done simple linear regression tests to see if there is a reason to expect a more parabolic relationship between knowledge distance and the choice of the MIP (modelled as dummy, supplier, customer, internal, research institute or university, in the dependent variable for this model). There is no parabolic relationship for any of them to be found. The linear effect however is statistically significant for internal (when knowledge distance is lower more often internal remains MIP) and a research institute (when knowledge distance is higher and the R&D prime objective is build-up of internal competencies).

With a large sized focal firm and a medium or small sizes supplier, the focal firm probably has the power over its supplier who thus works with the focal firm's internal R&D technology and processes; therefore, a recombination strategy is not necessary. For large focal firms, the supplier might need to adapt to the focal firm's internal strategy. Our dataset was too limited to split between large focal firms and smaller focal firms and to see whether this further explains the pattern found. For future study, it could be interesting to investigate firm size as an antecedent of both the focal firm as well as the partner.

At the project level, partners and customers are selected by the product management team, but we have to realize that for critical suppliers as well as lead customers, a long-term relationship endorsed by the executive management of the companies is likely to develop or envisioned for the future. Both in case of finding a customer as well as a supplier as the MIP, our expectation is that this could be a part of a long-term strategic collaboration endorsed by the executive management of a company with much investments in relational, non-contractual safeguards to reduce transaction cost. As this study considered the project level, a study that couples project level with long-term inter-organizational networks could shed further light on this.

Last, this study assumed that the R&D prime objective has been decided upon before the start of the NPD project. As a part of a stage-gated development process encompassing a group of projects changing over time, it is clear that the R&D prime objective, especially one that gets the highest priority in a specific project, has to do with market insights as well as with the phase of the development process. Future research could investigate this further.

## Conclusions

This paper explored how organizational competencies and the R&D prime objective of the focal firm are related with who becomes the MIP in NPD, with the most common options being a customer, a supplier, or the focal firm's Internal product and/or R&D team(s)s. In the current literature, very little is known about who the most important partner (MIP) is in an NPD project or what the MIP's dominant influence on the product specification leads to, especially in cases in which there are multiple external R&D partners, which was found to be the case in more than two thirds of our project sample. Thus far, much effort has been spent on studying partnership selection, but less is understood about who the MIP is (among these partners) and why.

In this paper, we built a model to explain in which cases a supplier or internal product and/or R&D team(s) becomes more important than a lead customer in driving the product specification. We validated our model using multinomial regression of 107 finalized R&D projects. The model was designed to assess how knowledge distance, external knowledge use, and R&D prime objective of the focal firm are related with MIP selection. Our regression analysis confirmed that projects with the focal firm itself as the MIP rather than a lead customer have on average a lower knowledge distance and a tendency to prioritize cost optimization, which is a TCE-based view. On the contrary, when the highest product performance is the main R&D prime objective, and there is an external technology critical for the product performance, a supplier will be relatively more likely to become the MIP. In that case, there is a need for the supplier's roadmap to be fully aligned with the focal firm. A supplier is more prone to become MIP if it provides a technology that is critical for the product or service and requires much of the supplier's expertise. Quite logically, this is associated with the focal firm pursuing a recombination strategy. We have found these results in a high tech setting, where the norm is to conduct a rather complex NPD with at least one but often multiple R&D partners. With the explication of MIP, we add to the Resource Dependence Theory a clarification on which R&D partner gains importance, and with that power and control, based on the focal firm's prior organizational competencies and R&D prime objective.

## Acknowledgments

This study is based on data which was collected during a study done with Professor Carla Koen, whose discussions and insights have helped me to gain insights for this study. The initial questionnaire was created by Thijs Peeters during his Ph.D. work and with his kind permission, we adapted it for this study. Inger Rempt modified the questionnaire from a paper to a web format in order to gather enough responses in as short period as possible. Olfa Marzouk merged addresses form all databases to allow the questionnaire to be sent out to many semiconductor professionals. I am grateful to both for their practical help. Finally, I thank the executive management of Imec for their support.

## Appendix 1: Parameter, construct, and source of questions

| # | Parameter | Construct | Answer type | Source | Original construct |
|---|---|---|---|---|---|
| | Name | What is the name of the company you work for? | Open | | |
| | Respondent Background | What is your function area? | Multiple options +open | | |
| | Respondent experience | For how long have you been working in your current position? | 0-1 years<br>1-3 years<br>3-6 years<br>6-10 years<br>Over 10 years | | |
| | Respondent experience | For how long have you been working in this industry? | 0-1 years<br>1-3 years<br>3-6 years<br>6-10 years<br>Over 10 years | | |
| | New technology | This project contained technology new to our company | Y/N | | New questions in this questionnaire, needed to identify if new technology is used and if so what kind of new technology. |
| | New technology | If Y: please fill in<br>new to the world technology/ new to this market technology/ new to our company and still developing in the world /new to our company but mature in other products/ | | | |
| **Recombination** | New technology | If Y: please fill in: we mainly developed the technology internally; we developed the new technology by receiving it from a partner making little changes, we developed the new technology by receiving it from a partner but significantly altering it, we co-created it with a partner, we mainly developed the new technology based on publicly available technology (for example open source software) | | | New question to identify if new technology has been mainly developed internally or externally. |
| | Participation | Who has participated in the NPD process?<br>*Internal sources:* Employees with daily attachment to product development and R&D; Employees without daily attachment to product development and R&D<br>*External sources:* Suppliers, Customers, Universities, Research institutions, Consultant, Competitor, Other | Y/N, how many + Multiple answers possible | (Praest Knudsen & Bøtker Mortensen, 2011) | Original construct, but deleted other employees in headquarters or subsidiaries (not orthogonal on either two answers) split universities and research institutions |
| | Participation | If yes to universities and/or research institutions, please fill in which one(s) | List of options + other, please fill in | | |
| **MIP** | Participation | Who was the most **Key partner** in the new product development project (only one answer) | One answer only, see 3.1 + other, please fill in | (Praest Knudsen & Bøtker Mortensen, 2011) | Original construct, but split universities and research institutions |
| | Participation | *Branch, only when external partner mentioned:* When most important partner was external, how satisfied were you with the cooperation? | 7 point Likert scale: 1 completely unsatisfied; 7 completely satisfied | | |
| | Participation | *Branch, only when external partner mentioned* For how many years are you collaborating with this partner already? | 0-2 years; 3-5 years; 5-10 years; more than 10 years | | |

| | | | | | |
|---|---|---|---|---|---|
| | Project size | How many people (in Full-time Equivalent, FTE) have been working on this project on its peak? | Number – specific | | |
| | Deadline | The main deliverables were on-time. | Likert 1-7, Strongly disagree to Strongly agree | | |
| | Deadline | If Y on product on market: the product was on the market at the planned volume production date | Likert 1-7, Strongly disagree to Strongly agree | | |
| | Knowledge distance | *Branch: Answer only when yes to question 2.1.: Please answer the following questions on the new technology/knowledge used in the project* | | | |
| **KD0** | Knowledge distance | To independently develop this new technology by our team, highly trained personnel would need to be hired. | Likert 1-7, Strongly disagree to Strongly agree | (Steensma & Corley, 2001) | Measuring *relatedness:* The extent to which the firm would need to have invested in trained personnel and equipment for independent development, as well as the relative cost of such development to independently develop this knowledge, highly trained personnel would need to be hired. |
| **KD1** | Knowledge distance | Little new investment in equipment or staff would be required of our firm to independently develop this technology. | Likert 1-7, Strongly disagree to Strongly agree | (Steensma & Corley, 2001) | Measuring *relatedness:* The extent to which the firm would need to have invested in trained personnel and equipment for independent development, as well as the relative cost of such development. **Little new investment in equipment would be required of our firm to independently develop this technology.** |
| **KD2** | Knowledge Distance | The cost to develop this technology independently would be greater than our previous development efforts | Likert 1-7, Strongly disagree to Strongly agree | (Steensma & Corley, 2001) | |
| **KD3** | Knowledge Distance | The TOTAL cost to develop this technology within our firm would have been significantly greater as compared to the average cost of other technologies that our firm has independently developed in the past | Likert 1-7, Strongly disagree to Strongly agree | (Steensma & Corley, 2001) | |
| | Uniqueness of novelty | *Branch: Answer only when yes to question 2.1.: Please answer the following questions on the new technology/knowledge used in the project* | | | |
| | Uniqueness of novelty | Many of our competitors had fundamentally similar technology. | Likert 1-7 | (Steensma & Corley, 2001) | Measuring *uniqueness*: The current prevalence [of the technology] within the industry **Many of our competitors had fundamentally similar technology.** |
| | Uniqueness of novelty | There were a limited number of organizations in our industry that possessed this technology. | Likert 1-7 | (Steensma & Corley, 2001) | Measuring *uniqueness*: The current prevalence [of the technology] within the industry **There were a limited number of organizations that possessed this technology.** |
| | Uniqueness of novelty | Few credible substitutes competed with this technology. | Likert 1-7 | (Steensma & Corley, 2001) | Measuring *uniqueness*: The current prevalence [of the technology] within the industry **Few credible substitutes competed with this technology.** |
| | Uniqueness of novelty | This specific technology was common within the industry. | Likert 1-7 | (Steensma & Corley, 2001) | Measuring *uniqueness*: The current prevalence [of the technology] within the industry **This specific** |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | **technology was common within the industry.** |
| | External knowledge decision criteria *(part of identification?)* | *Branch: Answer only when yes to question 2.1.: Please answer the following questions on the new technology/knowledge used in the project* | | | |
| | External knowledge decision criteria | We thoroughly investigated all options to get access to this technology, | 1 – not at all, 7 very much | | |
| | External knowledge decision criteria | Both internal development and external gathering were given equally attention when searching for technology | Likert 1-7 | | |
| | External knowledge decision criteria | What were the decision criteria (please select all that apply)? | Options: build-up internal competence for future, lowest overall cost, highest product performance, shortest time to market, no internal resources available+ other (open) | (Rechtin & Maier, 1997) | |
| **IS** | External knowledge decision criteria | What was the single most important criteria? Select only one | Options: build-up internal competence for future, lowest overall cost, highest product performance, shortest time to market, no internal resources available+ other (open) | (Rechtin & Maier, 1997) | |

## Appendix 2: Results of multinomial logistic regression

**Variables**

MIP most important partner

0 Other
1 Customer
2 Internal
3 Supplier
4 Research institute
5 University

KD Knowledge distance

continuous based on 3 Likert items; average 1-7

PO R&D prime objective

1 Build-up internal competence for the future
2 Lowest overall cost
3 Highest product performance
4 Shortest time to market
5 No internal resources available and other

Note: respondents that indicated they didn't know what the R&D prime objective and decision criteria for external knowledge use had been, were removed (4 in total, reducing N from 111 to 107).

Ekus_recom Recombination

0 – other (replication, internal); 1 – recombination applied in the project measured as co-creation.

## Results Stata

```
Multinomial logistic regression                   Number of obs   =        107
                                                  LR chi2(40)     =      82.49
                                                  Prob > chi2     =     0.0001
Log likelihood =  -112.6812                       Pseudo R2       =     0.2680
```

| MIP | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| **0** | | | | | | |
| PO | | | | | | |
| 2 | 70.36419 | 13572.89 | 0.01 | 0.996 | -26532.02 | 26672.74 |
| 3 | 66.31363 | 12361.74 | 0.01 | 0.996 | -24162.25 | 24294.88 |
| 4 | 31.01813 | 18349.76 | 0.00 | 0.999 | -35933.85 | 35995.88 |
| 5 | 43.05839 | 52254.57 | 0.00 | 0.999 | -102374 | 102460.1 |
| ekus_recom | 81.54516 | 7725.252 | 0.01 | 0.992 | -15059.67 | 15222.76 |
| kd | 32.47072 | 3756.273 | 0.01 | 0.993 | -7329.69 | 7394.631 |
| numb_partners | -15.44007 | 1807.626 | -0.01 | 0.993 | -3558.322 | 3527.442 |
| NT2_2Hownewwasthistechnol | -36.85145 | 5186.353 | -0.01 | 0.994 | -10201.92 | 10128.21 |
| _cons | -278.1558 | 31586.49 | -0.01 | 0.993 | -62186.54 | 61630.23 |
| **1** | | | | | | |
| PO | | | | | | |
| 2 | -2.718707 | 1.211662 | -2.24 | 0.025 | -5.093521 | -.3438934 |
| 3 | -.4929745 | .6603101 | -0.75 | 0.455 | -1.787159 | .8012096 |
| 4 | -.4556653 | .8114305 | -0.56 | 0.574 | -2.04604 | 1.134709 |
| 5 | -1.996964 | 1.428206 | -1.40 | 0.162 | -4.796196 | .802268 |
| ekus_recom | 1.037534 | .7278238 | 1.43 | 0.154 | -.3889745 | 2.464043 |
| kd | .3704358 | .204005 | 1.82 | 0.069 | -.0294066 | .7702781 |
| numb_partners | .3081732 | .2065177 | 1.49 | 0.136 | -.0965941 | .7129406 |
| NT2_2Hownewwasthistechnol | .251858 | .3234537 | 0.78 | 0.436 | -.3820995 | .8858155 |
| _cons | -2.443549 | 1.279035 | -1.91 | 0.056 | -4.950412 | .0633141 |
| **2** | (base outcome) | | | | | |
| **3** | | | | | | |
| PO | | | | | | |
| 2 | -22.029 | 59224.05 | -0.00 | 1.000 | -116099 | 116055 |
| 3 | 1.996272 | 1.211771 | 1.65 | 0.099 | -.3787553 | 4.3713 |
| 4 | 1.009348 | 1.46482 | 0.69 | 0.491 | -1.861647 | 3.880342 |
| 5 | -.1871284 | 1.800648 | -0.10 | 0.917 | -3.716333 | 3.342076 |
| ekus_recom | 2.481518 | .8438247 | 2.94 | 0.003 | .8276524 | 4.135384 |
| kd | .4957706 | .2801809 | 1.77 | 0.077 | -.0533738 | 1.044915 |
| numb_partners | .2058125 | .2751622 | 0.75 | 0.454 | -.3334954 | .7451205 |
| NT2_2Hownewwasthistechnol | .3575964 | .4293654 | 0.83 | 0.405 | -.4839442 | 1.199137 |
| _cons | -6.005963 | 2.017896 | -2.98 | 0.003 | -9.960966 | -2.05096 |
| **4** | | | | | | |
| PO | | | | | | |
| 2 | -23.72051 | 74386.61 | -0.00 | 1.000 | -145818.8 | 145771.4 |
| 3 | -1.238546 | 1.023708 | -1.21 | 0.226 | -3.244976 | .7678841 |
| 4 | -21.96991 | 25759.79 | -0.00 | 0.999 | -50510.24 | 50466.3 |
| 5 | -23.23303 | 43869.61 | -0.00 | 1.000 | -86006.09 | 85959.63 |
| ekus_recom | 2.014273 | 1.03495 | 1.95 | 0.052 | -.0141925 | 4.042738 |
| kd | 1.097481 | .4671456 | 2.35 | 0.019 | .1818921 | 2.013069 |
| numb_partners | .5209167 | .3452118 | 1.51 | 0.131 | -.155686 | 1.197519 |
| NT2_2Hownewwasthistechnol | 1.012773 | .5991552 | 1.69 | 0.091 | -.1615491 | 2.187096 |
| _cons | -9.070017 | 3.034565 | -2.99 | 0.003 | -15.01765 | -3.12238 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | | | | | | |
| PO | | | | | | |
| 2 | -24.06737 | 107311.7 | -0.00 | 1.000 | -210351.2 | 210303.1 |
| 3 | -.713302 | 1.155674 | -0.62 | 0.537 | -2.978381 | 1.551777 |
| 4 | -21.83271 | 39888.03 | -0.00 | 1.000 | -78200.93 | 78157.27 |
| 5 | .2118092 | 1.563728 | 0.14 | 0.892 | -2.853041 | 3.276659 |
| | | | | | | |
| ekus_recom | .3227565 | 1.371673 | 0.24 | 0.814 | -2.365674 | 3.011187 |
| kd | .1028015 | .3948712 | 0.26 | 0.795 | -.6711319 | .8767348 |
| numb_partners | .2243975 | .3860262 | 0.58 | 0.561 | -.5322001 | .980995 |
| NT2_2Hownewwasthistechnol | -.2324359 | .6641401 | -0.35 | 0.726 | -1.534127 | 1.069255 |
| _cons | -2.261638 | 2.324041 | -0.97 | 0.330 | -6.816675 | 2.293399 |

## Appendix 3: Validity of the model, Hausman and single respondent tests

IIA Seemingly unrelated estimation Hausman test

```
. suest .

Robust results for .                          Number of obs   =        107
```

| | Coef. | Robust Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| **0** | | | | | | |
| PO | | | | | | |
| 2 | 70.36419 | 2.343562 | 30.02 | 0.000 | 65.77089 | 74.95749 |
| 3 | 66.31363 | 2.242319 | 29.57 | 0.000 | 61.91876 | 70.70849 |
| 4 | 31.01813 | 2.221617 | 13.96 | 0.000 | 26.66384 | 35.37242 |
| 5 | 43.05839 | 2.477227 | 17.38 | 0.000 | 38.20311 | 47.91366 |
| kd | 32.47072 | 1.012205 | 32.08 | 0.000 | 30.48684 | 34.45461 |
| ekus_recom | 81.54516 | 2.679612 | 30.43 | 0.000 | 76.29321 | 86.7971 |
| numb_partners | -15.44007 | .7394961 | -20.88 | 0.000 | -16.88946 | -13.99068 |
| NT2_2Hownewwasthistechnol | -36.85145 | 1.762135 | -20.91 | 0.000 | -40.30517 | -33.39773 |
| _cons | -278.1558 | 7.802918 | -35.65 | 0.000 | -293.4492 | -262.8623 |
| **1** | | | | | | |
| PO | | | | | | |
| 2 | -2.718707 | 1.108702 | -2.45 | 0.014 | -4.891723 | -.5456914 |
| 3 | -.4929745 | .6647731 | -0.74 | 0.458 | -1.795906 | .8099568 |
| 4 | -.4556653 | .8574757 | -0.53 | 0.595 | -2.136287 | 1.224956 |
| 5 | -1.996964 | 1.222428 | -1.63 | 0.102 | -4.392878 | .3989499 |
| kd | .3704358 | .2032397 | 1.82 | 0.068 | -.0279066 | .7687782 |
| ekus_recom | 1.037534 | .727474 | 1.43 | 0.154 | -.3882888 | 2.463357 |
| numb_partners | .3081732 | .2118775 | 1.45 | 0.146 | -.107099 | .7234455 |
| NT2_2Hownewwasthistechnol | .251858 | .3369545 | 0.75 | 0.455 | -.4085607 | .9122767 |
| _cons | -2.443549 | 1.258431 | -1.94 | 0.052 | -4.910029 | .0229311 |
| **2** | | | | | | |
| PO | | | | | | |
| 2 | 0 | (omitted) | | | | |
| 3 | 0 | (omitted) | | | | |
| 4 | 0 | (omitted) | | | | |
| 5 | 0 | (omitted) | | | | |
| kd | 0 | (omitted) | | | | |
| ekus_recom | 0 | (omitted) | | | | |
| numb_partners | 0 | (omitted) | | | | |
| NT2_2Hownewwasthistechnol | 0 | (omitted) | | | | |
| _cons | 0 | (omitted) | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | | | | | | |
| PO | | | | | | |
| 2 | -22.029 | 1.407234 | -15.65 | 0.000 | -24.78713 | -19.27087 |
| 3 | 1.996272 | 1.307801 | 1.53 | 0.127 | -.5669698 | 4.559514 |
| 4 | 1.009348 | 1.527503 | 0.66 | 0.509 | -1.984503 | 4.003198 |
| 5 | -.1871284 | 1.520812 | -0.12 | 0.902 | -3.167865 | 2.793608 |
| kd | .4957706 | .2579034 | 1.92 | 0.055 | -.0097108 | 1.001252 |
| ekus_recom | 2.481518 | .8842783 | 2.81 | 0.005 | .7483648 | 4.214672 |
| numb_partners | .2058125 | .2897021 | 0.71 | 0.477 | -.3619932 | .7736183 |
| NT2_2Hownewwasthistechnol | .3575964 | .451923 | 0.79 | 0.429 | -.5281564 | 1.243349 |
| _cons | -6.005963 | 2.164635 | -2.77 | 0.006 | -10.24857 | -1.763356 |
| 4 | | | | | | |
| PO | | | | | | |
| 2 | -23.72051 | .9392199 | -25.26 | 0.000 | -25.56135 | -21.87968 |
| 3 | -1.238546 | .9205516 | -1.35 | 0.178 | -3.042794 | .5657018 |
| 4 | -21.96991 | 1.003948 | -21.88 | 0.000 | -23.93761 | -20.0022 |
| 5 | -23.23303 | 1.082288 | -21.47 | 0.000 | -25.35427 | -21.11178 |
| kd | 1.097481 | .531087 | 2.07 | 0.039 | .0565693 | 2.138392 |
| ekus_recom | 2.014273 | 1.047672 | 1.92 | 0.055 | -.0391265 | 4.067672 |
| numb_partners | .5209167 | .3148015 | 1.65 | 0.098 | -.0960829 | 1.137916 |
| NT2_2Hownewwasthistechnol | 1.012773 | .6210927 | 1.63 | 0.103 | -.2045459 | 2.230093 |
| _cons | -9.070017 | 3.29897 | -2.75 | 0.006 | -15.53588 | -2.604153 |
| 5 | | | | | | |
| PO | | | | | | |
| 2 | -24.06737 | .8789974 | -27.38 | 0.000 | -25.79018 | -22.34457 |
| 3 | -.713302 | 1.218816 | -0.59 | 0.558 | -3.102137 | 1.675533 |
| 4 | -21.83271 | 1.037418 | -21.05 | 0.000 | -23.86602 | -19.79941 |
| 5 | .2118092 | 1.372605 | 0.15 | 0.877 | -2.478448 | 2.902066 |
| kd | .1028015 | .3597154 | 0.29 | 0.775 | -.6022279 | .8078308 |
| ekus_recom | .3227565 | .9196397 | 0.35 | 0.726 | -1.479704 | 2.125217 |
| numb_partners | .2243975 | .2683583 | 0.84 | 0.403 | -.3015752 | .7503701 |
| NT2_2Hownewwasthistechnol | -.2324359 | .4260807 | -0.55 | 0.585 | -1.067539 | .602667 |
| _cons | -2.261638 | 2.225119 | -1.02 | 0.309 | -6.622791 | 2.099515 |

Checking for overrepresentation from a single company and single respondent bias

Model using complete dataset, i.e., 6 categories of MIP; base category MIP = customer

```
Multinomial logistic regression                   Number of obs   =        106
                                                  LR chi2(35)     =      80.81
                                                  Prob > chi2     =     0.0000
Log likelihood = -112.47641                       Pseudo R2       =     0.2643
```

| MIP | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| 0 | | | | | | |
| IS | | | | | | |
| 2 | 67.55059 | 12335.85 | 0.01 | 0.996 | -24110.28 | 24245.38 |
| 3 | 55.71471 | 7178.086 | 0.01 | 0.994 | -14013.08 | 14124.5 |
| 4 | 10.9395 | 19729.71 | 0.00 | 1.000 | -38658.57 | 38680.45 |
| 5 | 88.75592 | 1.08e+09 | 0.00 | 1.000 | -2.12e+09 | 2.12e+09 |
| 6 | 9.832296 | 41594.05 | 0.00 | 1.000 | -81513 | 81532.66 |
| kd | 38.15526 | 2085.32 | 0.02 | 0.985 | -4048.998 | 4125.308 |
| ekus_recom | 54.02032 | 4278.275 | 0.01 | 0.990 | -8331.244 | 8439.285 |
| _cons | -338.3458 | 18423.29 | -0.02 | 0.985 | -36447.34 | 35770.64 |
| 1 | (base outcome) | | | | | |
| 2 | | | | | | |
| IS | | | | | | |
| 2 | 2.964203 | 1.20681 | 2.46 | 0.014 | .5988991 | 5.329507 |
| 3 | .5173593 | .6437077 | 0.80 | 0.422 | -.7442847 | 1.779003 |
| 4 | .4003998 | .7886937 | 0.51 | 0.612 | -1.145412 | 1.946211 |
| 5 | .1734863 | 2.61e+08 | 0.00 | 1.000 | -5.11e+08 | 5.11e+08 |
| 6 | 2.180163 | 1.411172 | 1.54 | 0.122 | -.5856829 | 4.946008 |
| kd | -.4126444 | .2026871 | -2.04 | 0.042 | -.8099039 | -.015385 |
| ekus_recom | -1.410867 | .7697115 | -1.83 | 0.067 | -2.919474 | .0977396 |
| _cons | 1.425017 | 1.074021 | 1.33 | 0.185 | -.6800251 | 3.530059 |
| 3 | | | | | | |
| IS | | | | | | |
| 2 | -19.73259 | 67629.67 | -0.00 | 1.000 | -132571.4 | 132532 |
| 3 | 2.567589 | 1.132366 | 2.27 | 0.023 | .3481921 | 4.786986 |
| 4 | 1.426557 | 1.350905 | 1.06 | 0.291 | -1.221168 | 4.074283 |
| 5 | -.8613261 | 3.76e+08 | -0.00 | 1.000 | -7.38e+08 | 7.38e+08 |
| 6 | 2.067324 | 1.812943 | 1.14 | 0.254 | -1.485979 | 5.620627 |
| kd | .0729963 | .2633393 | 0.28 | 0.782 | -.4431392 | .5891318 |
| ekus_recom | 1.462764 | .671497 | 2.18 | 0.029 | .1466542 | 2.778874 |
| _cons | -3.619532 | 1.691266 | -2.14 | 0.032 | -6.934353 | -.3047125 |

| | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| **4** | | | | | | |
| IS | | | | | | |
| 2 | -21.57572 | 83605.35 | -0.00 | 1.000 | -163885 | 163841.9 |
| 3 | -.4739042 | .8564074 | -0.55 | 0.580 | -2.152432 | 1.204623 |
| 4 | -21.56962 | 28466.13 | -0.00 | 0.999 | -55814.15 | 55771.02 |
| 5 | -2.905225 | 5.43e+08 | -0.00 | 1.000 | -1.06e+09 | 1.06e+09 |
| 6 | -21.39128 | 49499.44 | -0.00 | 1.000 | -97038.51 | 96995.72 |
| kd | .5522845 | .3801826 | 1.45 | 0.146 | -.1928597 | 1.297429 |
| ekus_recom | .9677748 | .850051 | 1.14 | 0.255 | -.6982946 | 2.633844 |
| _cons | -4.230879 | 2.150402 | -1.97 | 0.049 | -8.445589 | -.0161691 |
| **5** | | | | | | |
| IS | | | | | | |
| 2 | -21.00196 | 108037.6 | -0.00 | 1.000 | -211770.9 | 211728.9 |
| 3 | -.3856972 | 1.116118 | -0.35 | 0.730 | -2.573247 | 1.801853 |
| 4 | -21.34434 | 37125.49 | -0.00 | 1.000 | -72785.97 | 72743.28 |
| 5 | 59.52254 | 7.17e+07 | 0.00 | 1.000 | -1.41e+08 | 1.41e+08 |
| 6 | -19.94155 | 68041.44 | -0.00 | 1.000 | -133378.7 | 133338.8 |
| kd | -.3072065 | .4431797 | -0.69 | 0.488 | -1.175823 | .5614097 |
| ekus_recom | -21.14676 | 31462.04 | -0.00 | 0.999 | -61685.62 | 61643.32 |
| _cons | -.0377848 | 2.209059 | -0.02 | 0.986 | -4.367461 | 4.291892 |

Randomly remove all but one sample per company.

*Sample set 0*: only keep the first observation from any company

```
Multinomial logistic regression                 Number of obs     =         91
                                                LR chi2(30)       =      66.95
                                                Prob > chi2       =     0.0001
Log likelihood = -93.407298                     Pseudo R2         =     0.2638
```

| MIP | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| **0** | | | | | | |
| IS | | | | | | |
| 2 | 19.60355 | 14886.91 | 0.00 | 0.999 | -29158.21 | 29197.41 |
| 3 | 4.36317 | 10924.65 | 0.00 | 1.000 | -21407.56 | 21416.29 |
| 4 | 3.609334 | 15861.59 | 0.00 | 1.000 | -31084.53 | 31091.75 |
| 6 | -58.94132 | 27888.12 | -0.00 | 0.998 | -54718.65 | 54600.77 |
| kd | 42.77199 | 3701 | 0.01 | 0.991 | -7211.056 | 7296.6 |
| recom | 60.75186 | 8680.799 | 0.01 | 0.994 | -16953.3 | 17074.8 |
| _cons | -320.8733 | 28061.23 | -0.01 | 0.991 | -55319.88 | 54678.14 |
| **1** | (base outcome) | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **2** | | | | | | |
| IS | | | | | | |
| 2 | 2.83227 | 1.235522 | 2.29 | 0.022 | .4106917 | 5.253847 |
| 3 | .7174715 | .699347 | 1.03 | 0.305 | -.6532235 | 2.088166 |
| 4 | .3169768 | .8320062 | 0.38 | 0.703 | -1.313725 | 1.947679 |
| 6 | 1.592093 | 1.330561 | 1.20 | 0.231 | -1.015758 | 4.199943 |
| kd | -.5250645 | .2224321 | -2.36 | 0.018 | -.9610233 | -.0891057 |
| recom | -1.224562 | .8135316 | -1.51 | 0.132 | -2.819054 | .3699307 |
| _cons | 1.920101 | 1.191639 | 1.61 | 0.107 | -.4154691 | 4.255672 |
| **3** | | | | | | |
| IS | | | | | | |
| 2 | -19.36684 | 50513.38 | -0.00 | 1.000 | -99023.78 | 98985.05 |
| 3 | 2.635437 | 1.211722 | 2.17 | 0.030 | .2605053 | 5.010369 |
| 4 | .8318647 | 1.571937 | 0.53 | 0.597 | -2.249074 | 3.912804 |
| 6 | 1.204096 | 1.760152 | 0.68 | 0.494 | -2.245737 | 4.65393 |
| kd | -.1056907 | .3197483 | -0.33 | 0.741 | -.7323858 | .5210045 |
| recom | 2.010631 | .8178399 | 2.46 | 0.014 | .4076941 | 3.613568 |
| _cons | -2.9963 | 1.87228 | -1.60 | 0.110 | -6.665901 | .673302 |
| **4** | | | | | | |
| IS | | | | | | |
| 2 | -20.52537 | 51580.04 | -0.00 | 1.000 | -101115.6 | 101074.5 |
| 3 | -.539872 | 1.072492 | -0.50 | 0.615 | -2.641918 | 1.562174 |
| 4 | -20.66599 | 20743.9 | -0.00 | 0.999 | -40677.95 | 40636.62 |
| 6 | -22.34219 | 35576.79 | -0.00 | 0.999 | -69751.58 | 69706.89 |
| kd | .9664275 | .603596 | 1.60 | 0.109 | -.216599 | 2.149454 |
| recom | 1.367952 | 1.143789 | 1.20 | 0.232 | -.8738336 | 3.609737 |
| _cons | -6.783189 | 3.47407 | -1.95 | 0.051 | -13.59224 | .0258635 |
| **5** | | | | | | |
| IS | | | | | | |
| 2 | -20.15124 | 66554.51 | -0.00 | 1.000 | -130464.6 | 130424.3 |
| 3 | -.457837 | 1.135786 | -0.40 | 0.687 | -2.683937 | 1.768263 |
| 4 | -20.97241 | 26110.28 | -0.00 | 0.999 | -51196.17 | 51154.23 |
| 6 | -19.12138 | 38280.38 | -0.00 | 1.000 | -75047.29 | 75009.05 |
| kd | -.4564 | .4565585 | -1.00 | 0.317 | -1.351238 | .4384383 |
| recom | -20.40201 | 21688.42 | -0.00 | 0.999 | -42528.92 | 42488.12 |
| _cons | .8574463 | 2.286046 | 0.38 | 0.708 | -3.623121 | 5.338014 |

The model remained statistically significant with the same explanatory power. Size of coefficients that we used in our model stayed close to the original model without changing directions. The same coefficients stayed statistically significant, except for recombination when MIP=2 (internal), where p becomes 0.13.

*Sample set 1*: Only keep the last observation from any company

| Multinomial logistic regression | Number of obs | = | 91 |
|---|---|---|---|
| | LR chi2(35) | = | 66.53 |
| | Prob > chi2 | = | 0.0010 |
| Log likelihood = -98.890847 | Pseudo R2 | = | 0.2517 |

| MIP | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---|---|---|---|---|---|---|
| **0** | | | | | | |
| IS | | | | | | |
| 2 | 67.05278 | 10716.52 | 0.01 | 0.995 | -20936.94 | 21071.05 |
| 3 | 56.08845 | 6630.853 | 0.01 | 0.993 | -12940.14 | 13052.32 |
| 4 | 53.076 | 10216.5 | 0.01 | 0.996 | -19970.89 | 20077.04 |
| 5 | 91.67713 | 1.52e+08 | 0.00 | 1.000 | -2.97e+08 | 2.97e+08 |
| 6 | -4.2924 | 35089.72 | -0.00 | 1.000 | -68778.87 | 68770.29 |
| kd | 39.25938 | 2049.387 | 0.02 | 0.985 | -3977.464 | 4055.983 |
| recom | 54.60614 | 2989.712 | 0.02 | 0.985 | -5805.122 | 5914.335 |
| _cons | -345.4134 | 17700.28 | -0.02 | 0.984 | -35037.32 | 34346.49 |
| **1** | (base outcome) | | | | | |
| **2** | | | | | | |
| IS | | | | | | |
| 2 | 2.431303 | 1.256285 | 1.94 | 0.053 | -.0309713 | 4.893577 |
| 3 | .5232588 | .6596941 | 0.79 | 0.428 | -.7697179 | 1.816236 |
| 4 | .2512635 | .8343573 | 0.30 | 0.763 | -1.384047 | 1.886574 |
| 5 | 1.630502 | 5.19e+07 | 0.00 | 1.000 | -1.02e+08 | 1.02e+08 |
| 6 | 1.135967 | 1.470124 | 0.77 | 0.440 | -1.745424 | 4.017357 |
| kd | -.4479806 | .2184896 | -2.05 | 0.040 | -.8762123 | -.0197489 |
| recom | -1.090794 | .8257623 | -1.32 | 0.187 | -2.709259 | .5276699 |
| _cons | 1.575032 | 1.135807 | 1.39 | 0.166 | -.6511085 | 3.801173 |
| **3** | | | | | | |
| IS | | | | | | |
| 2 | -23.41613 | 415656.3 | -0.00 | 1.000 | -814694.8 | 814648 |
| 3 | 2.518554 | 1.177242 | 2.14 | 0.032 | .211203 | 4.825906 |
| 4 | .8526024 | 1.551888 | 0.55 | 0.583 | -2.189042 | 3.894246 |
| 5 | .5769638 | 6.77e+07 | 0.00 | 1.000 | -1.33e+08 | 1.33e+08 |
| 6 | .9782803 | 1.732882 | 0.56 | 0.572 | -2.418106 | 4.374666 |
| kd | .0483261 | .2973196 | 0.16 | 0.871 | -.5344096 | .6310617 |
| recom | 1.734514 | .8038144 | 2.16 | 0.031 | .1590668 | 3.309961 |
| _cons | -3.514519 | 1.81635 | -1.93 | 0.053 | -7.0745 | .0454611 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **4** | | | | | | |
| IS | | | | | | |
| 2 | -25.41057 | 468494.6 | -0.00 | 1.000 | -918258 | 918207.2 |
| 3 | -.9137036 | .9759391 | -0.94 | 0.349 | -2.826509 | .9991018 |
| 4 | -20.51692 | 17963.09 | -0.00 | 0.999 | -35227.53 | 35186.5 |
| 5 | -1.335984 | 8.63e+07 | -0.00 | 1.000 | -1.69e+08 | 1.69e+08 |
| 6 | -22.13889 | 33140.45 | -0.00 | 0.999 | -64976.23 | 64931.95 |
| kd | .704767 | .4516937 | 1.56 | 0.119 | -.1805364 | 1.59007 |
| recom | 1.115971 | .9713754 | 1.15 | 0.251 | -.7878893 | 3.019832 |
| _cons | -4.884273 | 2.516438 | -1.94 | 0.052 | -9.8164 | .0478547 |
| **5** | | | | | | |
| IS | | | | | | |
| 2 | -23.79245 | 417815.3 | -0.00 | 1.000 | -818926.7 | 818879.1 |
| 3 | -.3528572 | 1.113931 | -0.32 | 0.751 | -2.536121 | 1.830407 |
| 4 | -20.32381 | 22727.24 | -0.00 | 0.999 | -44564.89 | 44524.24 |
| 5 | 56.30699 | 3.53e+07 | 0.00 | 1.000 | -6.93e+07 | 6.93e+07 |
| 6 | -18.14461 | 32284.42 | -0.00 | 1.000 | -63294.44 | 63258.15 |
| kd | -.3355009 | .443426 | -0.76 | 0.449 | -1.2046 | .533598 |
| recom | -19.95707 | 19805.73 | -0.00 | 0.999 | -38838.46 | 38798.55 |
| _cons | .1106592 | 2.197445 | 0.05 | 0.960 | -4.196255 | 4.417573 |

The model remained statistically significant, with slightly lower explanatory power (r2=0.25). Size of coefficients didn't change directions, most coefficients did not change significantly in size except for recombination (recom). The same coefficients stayed statistically significant except for recombination when MIP=2 (internal), where p becomes 0.19. The negative relation between applying recombination and the focal firm itself remaining the MIP should be seen as a lot less statistically robust compared to the positive relation between applying recombination and a supplier becoming the MIP.

# Chapter 3

# Close collaboration matters: Relating organizational competencies with external knowledge transfer and use


## Abstract

Open innovation (OI) is widely acclaimed for its potential to improve innovative output and firm performance. Still, this positive effect is disputed, as studies have also shown that it can have negative effects on R&D performance. This study aimed to explain these puzzling and sometimes contradictory results by focusing on the complementary role of the firm's own (internal) competencies, namely component and architectural competencies. At first sight, one would argue that higher organizational competencies are always beneficial, but prior studies have suggested that there is a risk that teams take up less external knowledge when they have a higher level of competence. In this case, certain architectural competencies are more important for innovation success than when initial component competencies are low. We explored how architectural and component competencies relate with the innovation performance of companies when working with an external partner, articulating an expanded resource-based view model depicting an interaction between architectural and component competencies. By examining 101 finished projects where high tech companies collaborated with a research organization, we found support for our hypothesis that more component competencies help improve external knowledge transfer and use only when certain architectural competencies are sufficiently available.



*Keywords*: knowledge transfer, external collaboration, NIH, open innovation, R&D, new product development, organizational competencies

## Introduction

Firms that conduct expensive, risky, and/or complex R&D are increasingly relying on collaboration with external sources of expertise to maintain or even increase their innovation performance (Cassiman & Veugelers, 2002; Morgan & Berthon, 2008). Steadily increasing complexity and development costs in high-tech industries ensured that external partnerships are here to stay. The percentage of R&D partnerships in new product development (NPD) is larger than 80% in pharmaceutical, information technology, and semiconductor industry (Chesbrough, 2006; Hagedoorn, 2002; Hagedoorn et al., 2000; Schuhmacher et al., 2013). Such “open innovation” is known widely for its potential to improve innovative output of the firm (Laursen & Salter, 2006) and prevent increasing R&D costs (Chesbrough & Garman, 2009). According to the open innovation paradigm internal R&D should be able to access and use technologies as needed by the company’s business and not wait for internal technologies to arrive. This means that they should be able to benefit from knowledge created outside the company, for example within an R&D organization, when the company strategy (which usually changes faster than the rhythm of basic research) demands it. As part of a policy to increase R&D efficiency per investment dollar, internal R&D should also not focus on developing technologies which are to be used by the whole industry, but don’t give a specific competitive advantage in the market place. Also external R&D organizations and companies can develop platforms, standards and building blocks for reuse over the entire industry at a fraction of the cost. The focal R&D partner however should be able to transfer the external knowledge efficiently and use it effectively in their own R&D. This does not always seem to be the case in practice and hence the positive effect of open innovation has also been disputed; indeed, some studies have shown negative effects on R&D performance (Praest Knudsen & Bøtker Mortensen, 2011). For a company that operates in an expensive, risky and complex R&D environment, it is extremely important to be able to benefit from open innovation and hence to be able to transfer external knowledge efficiently and to use it effectively in their own R&D development.

It is important to understand what makes a company successful in transferring and using knowledge out of collaborative R&D with an external R&D organization as companies use these type of collaborations to build up better component competencies quickly and efficiently. In general, negative attitudes towards external collaboration prevail (Eisenhardt & Martin, 2000; Herzog & Leker, 2010; Mortara & Minshall, 2011); hence, it is critical for the success of any open innovation strategy to overcome negative attitudes. (Mortara & Minshall, 2011) suggested that an organizational culture, which is more ready to accept ideas from outside and to take risks, may have a greater effect on the adoption of open innovation than the firm's specific innovation needs. Hence our research question is: *How do architectural and component competencies relate with external knowledge transfer and knowledge use when working with an external R&D organization?*

Currently, no resource-based model exists that coherently explains the sometimes positive and sometimes negative effects of open innovation on innovative performance. This paper aims to contribute to such an overall theory by looking in more detail into aspects of organizational competencies and their interaction with each other, and how this may explain which firm are better able to use external collaboration results.

In a resource-based view, the possession of unique 'competencies' or 'capabilities' is an essential source of enduring strategic advantage (Dyer, 1997; Kahn et al., 2013; Kerssens - van Drongelen & Bilderbeek, 1999). (Henderson & Cockburn, 1994) proposed that organizational competencies can be divided into architectural and component competencies. In their definition, component competencies represent skills or assets specific to particular local activities within the firm, including unique disciplinary expertise. The architectural (or integrative) competencies allow a firm to use its component competencies by integrating them in new and flexible ways and to develop new architectural and component competencies as required. Architectural competencies include the communication channels, information filters, and problem-solving strategies that develop between groups within a problem-solving organization as well as the other organizational characteristics that structure problem-solving within the firm and that shape the development of new competencies: the control systems and the organizational culture (Kerssens - van Drongelen & Bilderbeek, 1999). Both types of competencies might lead to a competitive advantage, but architectural competencies are especially helpful in building up and transferring from outside new knowledge absent specific knowledge of the particular domain of R&D. Intuitively, architectural competencies should play a less important role when the focal firm's team is already competent in the area of the R&D collaboration. However, several studies have suggested that teams might take up less external knowledge when they are more competent themselves (Dyer et al., 2001; Witzeman et al., 2006). One of the reasons can be that there is simply less to learn from external partners when teams are more technically competent themselves. Professional pride and "not-invented-here" syndrome might also lead to behavior of individuals and teams that counter effective external knowledge transfer and use. However, there might be good reasons from a managerial point of view to still work with external R&D

partners even in case of high internal technical competencies in a certain field. For example, it is a widely chosen strategy to only develop product differentiators in-house and to let basic functionality be developed externally (with a shared cost factor) to reduce overall R&D cost. In these cases, certain architectural competencies could turn out to be even more important for innovation success than when initial component competencies are low.

This study provides several contributions to the literature. To start, it offers an updated resource-based model to expand the RBV theory, which also explains unexpected (negative) results of previous studies on the outcomes of open innovation. We did this by starting with separate effects of component and architectural competencies, as done in previous literature, and subsequently considering their interactive effect. Furthermore, we validated the interaction effect between the component and architectural competencies in this updated resource-based model. Additionally, based on our dataset, we derived quantified information on the innovation outcome for the focal firm that collaborates with an external research organization, which have thus far been described only in a qualitative manner. Finally, for practitioners, we give clear suggestions on how to reduce the negative bias towards external knowledge based on the organizational competencies that their firm and R&D team have at the time they start an OI project.

The empirical results of this study are based on completed research projects done between industrial partners and a research organization over a period of ten years.

## Literature & hypotheses

### Innovation outcome & knowledge transfer

When an R&D team of a company, called the focal R&D partner, is working together with an external R&D team of an external research organization, the overall success of the collaboration can be seen as the use of the external research project's tangible and intangible results, or external knowledge, in the focal partner's further research and/or product innovations as well as the IP created within the external R&D project or at the focal firm during or just after the collaborative project. This *Innovation Outcome* (IO) includes not only direct IP generation from the external R&D project and the use of that by the focal firm, but also tacit knowledge and the learning of new component competencies. A positive innovation outcome relates to an increased R&D performance within the focal firm as it measures the learning of new component competencies and tacit knowledge.

Companies work with a research organization to develop better component competencies in a certain field. According to (Chesbrough, 2006), external R&D can create significant value, but internal R&D is needed to claim some portion of that value. Hence, to increase the NPD uptake of external research results as well as the internal generation of new research results, it is useful to have an internal R&D team in parallel with these external research collaborations. Several studies have confirmed that internal and external sources have to be combined to improve the innovative performance of companies and that internal R&D resources are indispensable to effectively exploit external knowledge (Chesbrough & Crowther, 2006; Cohen & Levinthal, 1989; Poot et al., 2009; Vanhaverbeke, Van de Vrande, & Cloodt, 2007), and moreover these studies also explicitly observed that significant increases in the degree of collaboration with external partners were accompanied by significant increases in the degree of collaboration with internal partners. In line with the original thinking of Chesbrough we assume that having an internal R&D team helps to create higher IO amongst external research collaborations with research organizations as the internal R&D team will be able to assimilate and integrate the external knowledge better and adjust it to the specific product application at hand. Without an internal R&D team the external knowledge cannot be absorbed efficiently as the translation between the product at hand and the external knowledge has to be made without a full understanding of the technical consequences. We will validate this given from literature in our research model.

While this sounds very straightforward, more complicated mechanisms are at play with such an internal R&D team. Indeed, the internal R&D team might start to compete with the external team, or there might be other knowledge transfer barriers. To increase IO, knowledge transfer between the external project team and the partner must be efficient and complete. However, knowledge transfer barriers are manifold and although they are similar, different classifications exist in the literature (Roussel et al., 1991; Sethi, 2000).

**Not-invented-here syndrome**

The behavior of knowledge receivers has not been well understood thus far (Kathoefer & Leker, 2012). In the case of knowledge transfer from an external R&D project to the R&D team, individuals in the R&D team can reject the new knowledge for different reasons, from professional pride to maintaining status quo and the not-invented-here syndrome (NIH). Not-invented-here syndrome can be seen as a profound attitude-bias towards knowledge derived from outside from the perspective of the individual (Katz & Allen, 1982; Kostova & Roth, 2002). Research on NIH postulates that individuals have a generally negative attitude towards knowledge, ideas, and technologies of external origin (Laursen & Salter, 2006). When this predisposition holds, irrespective of the objective value of an external input for the innovating company, an individual is said to be affected by the NIH syndrome. Especially when the component competencies of a firm are already medium to high, it is easier to reject external knowledge, as “we can do this ourselves” sounds like an acceptable argument and makes it easy to avoid further investigating the external input. This is why innovating organizations in a collaborative or open R&D environment have to take measures in their organizational structures which counter the individual predisposition to think more negatively about external knowledge (Kathoefer & Leker, 2012). Higher architectural competencies in a firm can reduce the NIH syndrome, just as they reduce organizational, contextual, and spatial boundaries by forming an integrated R&D team. These are described in the upcoming paragraphs.

## Architectural competencies

### Breadth and frequency of interaction

Henderson and Cockburn (1994) paid special attention to the communication and spread of information within a company. The author found support that companies that have better internal communication and a broader spread of information, as well as a distributed way of decision-making, are more successful in absorbing architectural or integrative improvements. It is hence likely that more frequent as well as wider interaction in terms of different groups of personnel involved is an indication of more distributed decision-making. Thus, we measured interaction by looking at the frequency of interaction and involvement with a company’s CTO/research division as well as at the frequency of interaction with a company’s business unit. Because all partners involved in the projects investigated in this study were offered the possibility to have almost unrestrained interaction with the research organization’s researchers, the breadth of interaction with or involvement in different units and the frequency of interaction is highly dependent on the routines of the focal firm and the architectural competencies of the organization. We believe that higher interaction frequencies with both CTO/research as well as the business unit will lead to better knowledge transfer because of better communication and spread of external knowledge within the focal company.

Based on the RBV theory and the findings of (Kerssens - van Drongelen & Bilderbeek, 1999), we stipulated that higher architectural competencies will lead to better innovation outcomes and that higher, more frequent and more widely spread Interaction increases the innovation outcome. We validate this literature with our research model.

**Recombination**

Creating new knowledge involves combining internal knowledge and external knowledge in a novel fashion (Bapuji & Crossan, 2004; Bierly & Chakrabarti, 1996; Vera & Crossan, 2004). We looked at two specific drivers of architectural competence, interaction and knowledge. One can distinguish three main categories of integrating external knowledge with internal knowledge. This ***external knowledge use*** **(*EKU*)** can be defined as follows:

- Complementary i.e., knowledge is developed mainly internally. It might be complemented by external knowledge, which then has to fit into the internal knowledge components with little or no adaptation to them;
- Replication, defined as using external knowledge in the state in which it was acquired with little or no adaptation (Szulanski et al., 2004); and
- Recombination, defined as substantial performance-enhancing modifications to both existing internal knowledge components as well as external knowledge components (Gruber et al., 2012).

Many studies have emphasized that firms must be capable of absorbing and using the knowledge effectively if they are to benefit from external knowledge (Bönte, 2005; Griffith & Harvey, 2004). For external knowledge use, using recombination is the highest form of dealing with external technology as it intrinsically means that a high level of internal understanding of the external technology is needed.

**Component competencies**

A number of researchers have suggested that locally embedded knowledge and skills are a source of enduring competitive advantage (Dyer, 1997; Kerssens - van Drongelen & Bilderbeek, 1999). In the field of high tech and pharmaceutical research, these component competencies offer two important possibilities: 1) unique disciplinary expertise and 2) application, process, or other domain-specific knowledge. While many studies have suggested that a high component-based competence helps absorb external knowledge in that particular disciplinary area, other studies have suggested that having high component-based competencies within the field of the external research partnership does not necessarily mean that the knowledge emerging from this R&D effort is easily assimilated and integrated within the NPD of the company (Burcharth et al., 2014; Dyer et al., 2001). On the contrary, some studies have suggested that teams might take up less external knowledge when they are more competent themselves. In earlier research on innovation strategy, including organizational competitive advantages, this phenomenon has either not been addressed (Agrawal et al., 2010) or it has been addressed but with the underlying mechanisms of NIH being described in a rather anecdotal fashion (Kathoefer & Leker, 2012). A systematic conceptualization of NIH has only recently been published (Antons & Piller, 2014), but the operationalization and investigation of NIH are still lacking.

Indeed, when the R&D team has a high component competence before the external project starts, the perceived need to transfer knowledge from outside is smaller and NIH, professional pride, and maintaining status quo (“we are already good at it and we can do this ourselves”) will sooner prevail if no countermeasures are taken. Hence our first hypothesis is:

*H1: Amongst external R&D collaborations with a research organization, an R&D team within the company with higher pre-project innovation quality is associated with a worse innovation outcome.*

**Integrated R&D team**

In acquiring and applying external knowledge, firms face several difficulties that arise due to the complex nature of knowledge consisting of not only explicit, but also tacit dimensions (Nonaka, 1994). Explicit knowledge is codifiable and thus easier to acquire, whereas tacit knowledge is non-codifiable, sticky, and difficult to acquire (Kahn et al., 2013; Roussel et al., 1991). While explicit knowledge can be acquired by appropriating such things as documents, design databases, and manuals, tacit knowledge includes the nuances of knowledge creation and use gained through trial and error (Nonaka & Von Krogh, 2009). This tacit knowledge is usually not documented; hence, acquiring and using it is very difficult. Knowledge is embedded and situated in practice (Cook & Brown, 1999; Orlikowski, 2002). In communities of practice, knowledge gets shared and (re)interpreted, and these (re)interpretations make the knowledge dynamic. Unlike explicit knowledge, which is widely and easily shared, dynamic and situated knowledge is available only to the members of the community in which it resides. It is often acquired by observing other members as they use the knowledge in action (Nadler, Thompson, & Boven, 2003). To improve the transfer of knowledge, it is a recommended practice to actively collaborate with external research colleagues (Cockburn & Henderson, 1998). Active participation in a research partnership entails that employees from the company contribute to the research partnership by not only agreeing to shared objectives, but also implementing a part of these objectives as a part of the day-to-day team activity. Passive participation means that the company researchers will be receiving and listening to knowledge. Active versus passive participation evolves out of both existing company routines as well as a deliberate choice of the company's management of that particular research partnership.

For external research projects with an external research team, an integrated R&D team, where R&D employees of the focal company are a direct and integral part of the external research team, automatically enforces active participation. To be an integral part of the external R&D team, the R&D employees of the focal company reside on the premises of the external R&D organization, hence we call them residents. When companies choose to form integrated R&D teams that include residents from their own organization, the need for a recombination strategy of external knowledge usage is also expected to be much lower. In fact, integrated R&D teams will diminish the difference between internal and external knowledge over time, as the residents internalize the external knowledge. On top of that, boundaries between "them" and "us" being part of the NIH view are explicitly reduced, and common objectives and successes become the norm for the researchers involved from both the company as well as the external research provider. Hence, we stipulated that an integrated R&D team will improve knowledge transfer and as such define hypothesis 2. When an integrated R&D team is mainly there to make communication easier, one could argue that a single resident will be enough. However, when the intention is to have a true recombined approach in research, at the risk of higher spillovers to the research organization, more residents should improve the innovation outcome.

*H2: Amongst external R&D collaborations with a research organization, an integrated R&D team is associated with a better innovation outcome.*

While the advantages of active participation in acquiring tacit knowledge are clear from the discussion above, objections against full integration of company researchers with external research teams have also been raised. The two most prominent perceived disadvantages are that the transfer of tacit knowledge is not a one-way street; indeed, the spillover of a company's knowledge to the research organization, and with that to potential competitors, will take place as well. The second prominent disadvantage is that an integrated R&D team bears high costs, and to some extent, additional resources are needed to achieve this. Hence, looking into the benefits versus the potential costs of high integration of research teams gives important directions to the organization of research alliances and an integrated R&D team might not always be a realistic or the best option. Working from a distance might be selected to avoid knowledge spillover to the research organization and/or high costs, but a company of course still wants to gain the maximum from the external knowledge. Here, higher architectural competencies can help. A company that has high architectural competencies is able to assimilate and integrate external knowledge more fully and more completely while reducing knowledge spillover risks and the high costs of an integrated R&D team.

*H3: Amongst external R&D collaborations with a research organization the interaction of architectural competencies and pre-project innovation quality on the innovation outcome is positive.*

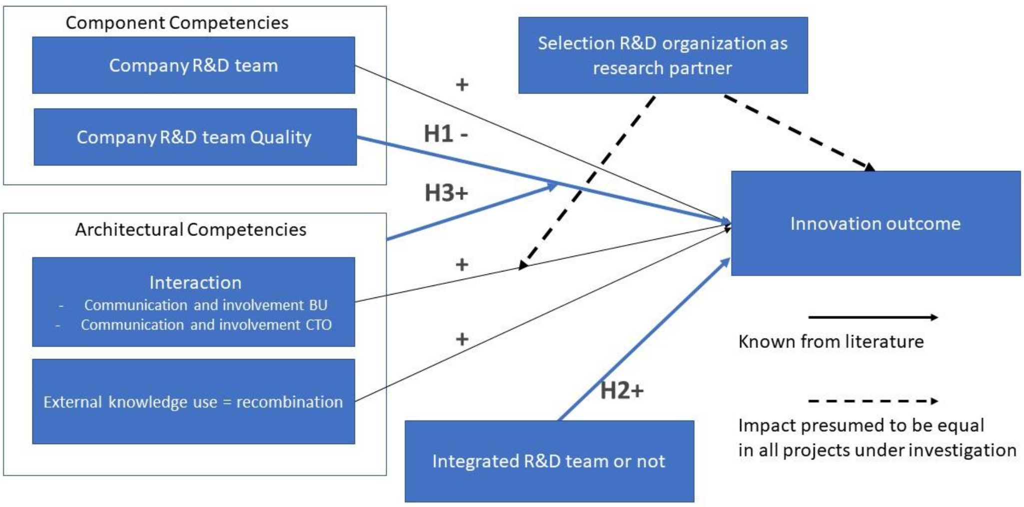


*Figure 6. Theoretical model.*

Figure 6 shows our complete theoretical model. In Table 6, we show a summary of how organizational competencies are expected to relate with innovation outcomes. Table 7 summarizes the hypotheses.

*Table 6*
*Expected Effects of Organizational Competencies on Innovation Outcome*

| Organizational competencies | Low architectural competence | High architectural competence |
|---|---|---|
| Low component competence | External research collaborations with research organizations have only chance of success when measures are taken to reduce contextual, spatial, and organizational boundaries, for example, using an integrated R&D team. | External research can be used to speed up internal component competence development. Having or creating an own R&D team in parallel with the external research efforts to reduce the contextual boundaries is an important factor to ensure that the new knowledge gets sufficiently transferred to and embedded within the organization for the future. |
| High component competence | While contextual boundaries have been reduced, NIH and hostility towards knowledge transfer can significantly reduce post innovation outcome or even lead to no knowledge transfer at all, especially when there is ego-defensive or ownership bias at play for the individual researchers within the company. | True co-creation becomes possible; innovation outcome can be maximized. |

*Table 7*
*Hypotheses Summary*

| Nr. | Hypothesis |
|---|---|
| H1 | Amongst external R&D collaborations with a research organization, an R&D team within the company with higher pre-project innovation quality is associated with a worse innovation outcome. |
| H2 | Amongst external R&D collaborations with a research organization, an integrated R&D team is associated with a better innovation outcome. |
| H3 | Amongst external R&D collaborations with a research organization, the interaction effect of architectural competencies and pre-project innovation quality on the innovation outcome is positive. |

## Method

In the Smart Electronics Division of Imec 335 (applied) R&D projects were completed over a period of 10 years, from 2004-2014. Unfortunately, the data from these projects are incomplete. For the oldest projects, the responsible technical and business officers were not always working at Imec anymore; hence, no additional data could be collected. For some of the newest projects, the data which needs to be collected that surpasses the end of the project, i.e., patent applications after the end of the project, is not yet available. We managed to have complete and validated data for 101 out of the 335 projects, to the best knowledge and ability of the authors and internal Imec responsible business, IP, and technical persons. Imec is an independent, non-profit research organization, one of the top three worldwide in the area of Nano-electronics. Imec started in 1984, and it has grown successfully over the years into a world-recognized research organization with more than 200 industrial partners covering the complete semiconductor ecosystem. In 2015, Imec's revenue was over 350 million Euro, with approximately 1,300 employees on payroll and 600 residents. The former Smart Electronics Division (reorganization since has changed the divisions within Imec) conducted R&D on applications, architectures, algorithms, circuit, and components, for example, on connectivity and the Internet of Things, in different application domains but also in the new field of bioelectronics, where bio fluidics and electronics meet, or in the personal biomedical engineering field where healthcare and electronics meet. At Imec, all R&D partners are offered the possibility to have almost unrestrained interaction with Imec’s researchers.

For the completed and validated projects in the database, we have a sample size of 101 projects executed by 84 different industrial partners from the worldwide semiconductor industry, mainly fabless and IDMs, but also with a few semiconductor manufacturers, IP providers and tens of application partners (OEMs). The partnerships are distributed worldwide, and larger companies dominate. The fees that the industry pays for the collaboration span from relatively small amounts (for example, an initial feasibility study preceding a larger collaboration) to more than many millions of euros per year, with a majority of contracts exceeding one million euro. The advantage of using this internal database is that the collected data available within Imec is impossible to collect from public sources. Additionally, from the perspective of Imec, the quality of the research results; the operations, including communication and transfer process between the company; and the research center were similar in all research projects. To the author’s best knowledge, such data has never been analyzed before. The database contains information about the project start and end date, the responsible business, technical officers from Imec, and the patent categories in which Imec filed patents for this research field. This data is complemented by factual data collected from the responsible business and technical officers, who normally have a meeting with the R&D focal firm at least once a month to track project progress, on the following:

- an indication of the amount of technical interaction between the company and Imec;
- the external knowledge use strategy of the company;
- interaction of CTO/central research and the frequency of interaction;
- interaction of a Business Unit and the frequency of the interaction;
- whether the company had its own R&D team in the same technical area as the collaboration during the project execution;
- whether there was an integrated R&D team and if so, the number of residents on the project.

The additional data was collected via individual interviews and questionnaires with 10 separate individuals from business and program management. The data collected is described in Appendix 1.We have extended the database by including information about the patent applications done in the field of interest by the company before, during, and after the research collaboration for 10 years, starting three years before the start of the collaboration. To look into the relevant classes, the classes where Imec submitted patent applications for a particular research area were considered to be relevant for that research area. Note that for collaborations that ended recently, not enough time passed since the collaboration; hence, the patent application results from after the project end date cannot be used. We have also measured the number of shared patent applications, i.e., patent applications done by inventors of both the company as well as the research organization. This data analysis was done using Orbit tools (Questel, 2015).

Besides all this factual data, two other pieces of data, which are potentially less objective, were collected from the business and technical officer responsible for the research project: 1) the use of the licensed technology, e.g., the knowledge generated in the project and in the end used in a product, and 2) the overall success of the collaboration from the perspective of customer, e.g., the industrial partner. The answers regarding the use of the licensed technology in a product are believed representative, but there are two issues: a) in certain cases, the results can be used in product development without the research organization being aware; hence, leading to underreporting of positive transfer to product, and b) it can take up to three years before research results are being used in a product; hence, projects that have recently been finalized might have a negative answer on use of licensed technology in a product while in fact, the results will in due time be taken up in a product of the company. This is again underreporting of positive knowledge transfer results. It is important to note that no over reporting of successful transfer results can take place.

Finally, the business and project officers were asked about an overall evaluation of the project success, described as a success from the perspective of a customer, i.e., the industrial partner. To reduce any chances on a positive bias,

a) answers were collected individually after the end of the project;

b) they were not shared amongst others; hence, there are no performance implications for any of the participants to speak up and;

c) whenever possible, answers were collected individually from two persons, both business as well as technical, per project.

The inter-rater reliability was very high, in more than 75% the answers were exactly the same, while in the remaining cases, the answers were very close (maximum one point difference on a 5-point Likert scale). In no case the business officer found a project successful while the technical officer found it unsuccessful, or the other way around.

Besides selecting a response on a Likert scale ranging from 1 to 5, participants could comment on the overall evaluation result. The comments, which were mainly indicating the success of results being used in products or having highly innovative IP output, give the author more faith in the subjective evaluation of the business and technical officer involved. The results from experts involved have been criticized in the past as not necessarily valid because of bias. To validate these subjective scores, we correlated the overall success, as indicated by the business and technical officers, with two pieces of factual data which is without a doubt a sign of successful transfer of knowledge results. Specifically, we asked:

a) Was the knowledge used by the focal firm in research and/or a product afterward? As can be seen in the analyzed OLS models later, this is highly related with the success of the project for the R&D partner as perceived by the Imec officers and explains about 12% of the outcome.
b) Was the number of patent applications in the field of interest higher up to three years after the start of the project than up to three years before the start of the project?

The variable to indicate an increase in patent applications was defined as:

$patentapp_{increase} = (-patentapp_{t-3} - patentapp_{t-2} - patentapp_{t-1} + patentapp_{t} + patentapp_{t+1} + patentapp_{t+2})/((1 + patentapp_{t-3})$ if !missing($patentapp_{t-3}$))

The numerator simply counts whether the number of patent applications is larger during the project than before while the denominator scales the outcome as patent application numbers differ widely per company. Note that the addition of 1 in the denominator is necessary if a company did not patent in this specific area at all three years before the start of the project[3]. With t as the start year of collaboration; classes included are the classes in which Imec has filed most of its patents for this particular research field, i.e., the patent classes believed to be relevant for this research collaboration or otherwise formulated for the component competence.

In Table 8 we report the variables which we use to investigate the level of organizational competencies. In Table 9 an explanation of the variables we use in the OLS model is given. Table 10 gives the descriptive statistics.

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[3] In several projects patent applications were not applicable as the project focused on mathematics, physics or methodologies. These projects were not taken into account for the regression (i.e. then there is missing($patentapp_{t-3}$)). Projects where patent applications were applicable data was set to 0 when no patent applications were found. Projects where patent applications were applicable were taken into account, even when all data was 0.

*Table 8*
*Variables Used to Investigate the Level of Organizational Competencies*

| Component competence | Architectural competence | Innovation Strategy |
|---|---|---|
| Having an internal R&D team on the area of knowledge | Interaction being broader within the company CTO/Research and/or BU/BL | Integrated research project assimilating company members as part of the external research activity |
| Internal Quality of Research before start of project | A Recombination Strategy for External Knowledge Use | |

*Table 9*
*OLS Model, Explanation of the Variables*

| | | Scale |
|---|---|---|
| 1 | Innovation outcome | Likert 1-5; how successful was the partnership in terms of IP generation, knowledge transfer to, use of knowledge by the industrial partner |
| 2 | CTO/research interaction | 0 (no involvement) – 2 (mainly involvement) |
| 3 | BU/BL interaction | 0 (no involvement) – 2 (mainly involvement) |
| 4 | Own R&D team | 0 = Company has no R&D team specifically for this technology/project; 1= R&D team for this specific technology or project |
| 5 | Residents | Integer; number of company researchers integrally integrated in the research project |
| 6 | Used in product | 0 unclear if used at all<br>1 only take-up in research<br>2 use in product development within 3 years after start<br>3 use in product development within 1 year after start |
| 7 | Research team quality | 0 if no patent applications three years before start of project in area of the project; 1 if there are patent applications in the area of the project before the start date; research team quality =0 when there is no R&D team |
| 8 | Recombination | 0 Internal/Replication/Other<br>1 Recombination |

*Table 10*
*Descriptive Statistics, Innovation Outcome*

| | | Mean | SD | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Innovation outcome | 3.796 | 1.166 | 1.000 | | | | | | | |
| 2 | CTO/research involvement | 1.126 | 0.776 | 0.038 | 1.000 | | | | | | |
| 3 | BU/BL involvement | 1.340 | 0.767 | 0.309 | -.656 | 1.000 | | | | | |
| 4 | Own R&D team | 0.920 | 0.273 | 0.400 | -.194 | 0.382 | 1.000 | | | | |
| 5 | Residents | 0.870 | 1.518 | 0.343 | 0.067 | 0.000 | 0.132 | 1.000 | | | |
| 6 | Used in product | 1.348 | 0.937 | 0.314 | -0.157 | 0.270 | 0.233 | 0.123 | 1.000 | | |
| 7 | Research team quality | 0.696 | 0.461 | 0.057 | 0.198 | -0.082 | 0.156 | 0.054 | .165 | 1.000 | |
| 8 | Recombination | 0.315 | 0.467 | 0.276 | 0.098 | 0.150 | 0.177 | -0.020 | 0.054 | 0.151 | 1.000 |

## Results

We first validated the dependent variable by establishing that success of the collaboration, as perceived by the business and technical officers of Imec, is, in fact, a reasonable estimate of the IO. From the results in Table 12, it can be seen that the increase in patent applications within the relevant field and the application of the results to product development strongly correlate with more positive evaluation results. However, we also expected less tacit knowledge transfer, which supports innovation capability in the longer term, even outside the direct field of collaboration. Based on the results of this validation test, presented in Table 12, we now feel comfortable using the evaluation result, which indicated that the research collaboration was successful in terms of knowledge transfer to and knowledge utilization by the company, as an indication of the actual innovation outcome (IO).

We test our model by evaluating the specific characteristics of a company's behavior in terms of architectural capabilities and assessing their correlations with IO. Explanation of the variables can be found in Table 9 and Table 11. The descriptive statistics are found in Table 10.

As the correlations between different variables are low, we do not expect any issues with multicollinearity. We have done extensive OLS analysis, comparing F-tests and adjusted $R^2$ of our models to determine which independent variables are most significant for the innovation outcome of the collaborative project at hand. In Appendix 2 we list an elaborate overview of these models.

Originally, we model with the whole group of projects and we find that the number of residents significantly positively changes the innovation outcome. We split the group between integrated and non-integrated R&D teams, as we expected that this would change the effect of the different independent variables. This turned out to be true, as we found that the best fitting and most valid model is different for projects with or without residents or an integrated R&D team. Furthermore, we found that the number of residents was significant; hence, we used the actual number of residents in our further models and not the dummy variable.

*Table 11*
*Descriptive Statistics, Success of Collaboration*

| | Scale | N | Mean | SD | Suc. of Coll | Patent Appl. Increase | Results used in product dev. |
|---|---|---|---|---|---|---|---|
| Success of collaboration | Likert 1-5 | 145 | 3.724 | 1.227 | 1.000 | | |
| Patent applications increase | Floating number | 207 | -0.051 | 0.972 | 0.169 | 1.000 | |
| Results used in product development | 0 unclear if used at all<br>1 only take-up in research<br>2 use in product dev. within 3 years after start<br>3 use in product dev. within 1 year after start | 149 | 1.349 | 0.972 | 0.323 | -0.083 | 1.000 |

*Table 12*
*The Relationship Between Success of Collaboration and Patent Application Increase and Use of the Results in Product Development*

| | Innovation outcome |
|---|---|
| Results used in product development | 0.432***<br>(0.115) |
| Patent application increase | 0.091**<br>(0.042) |
| Constant | 3.220***<br>(0.184) |

*Number of obs.= 109, Adjusted $R^2$=0.127. OLS estimation: *, **, *** indicate significance at 10%, 5% and 1% levels, respectively for two-tailed test. Standard errors appear in parentheses.*

**Innovation outcome of R&D projects without residents**

We find the innovation outcome of projects without residents indeed depends highly on the organizational competencies prior to the start of the project. It is important to have a high level of interaction with the BU, with a coefficient of 0.45 (p=0.018). We find support for our hypothesis 1 that a higher R&D team quality before the start of the project is negative for the innovation outcome of the project with a coefficient of -1.30 (p=0.000). This can be partially compensated by using recombination. The quality of R&D team*recombination mediation effect has a coefficient of 0.88 (p=0.007). The other partial compensation for the negative effect of prior R&D team quality is a high level of interaction with CTO/research, coefficient is 0.565 (p=0.011). With this, we find support for hypothesis 3, that strong architectural competencies moderate the negative effect of post-project R&D team quality until it ceases to exist.

### Innovation outcome of R&D projects with residents

The mean innovation outcome was higher in projects with residents (4.1 versus 3.4 out of a maximum of 5), indicating that these integrated research projects are generally very successful. We find that residents always have a positive and statistically very significant effect on the innovation outcome. In integrated R&D teams, more residents on-site of the research organization further improve the innovation outcome ($\beta=0.22$, $p=0.011$) and with that we find support for hypothesis 2. Projects with integrated R&D teams are less dependent, but not independent of prior architectural competencies. Recombination is not a factor of interest anymore, which is expected as integrated R&D teams automatically lead to a form of co-development. The best matching model indicates that a high level of interaction with CTO/Research of the focal firm is highly beneficial in case of integrated R&D teams, especially when prior R&D team quality was low. The coefficient is 3.27, $p=0.001$. This effect becomes significantly lower when the focal firm R&D team already had R&D quality in the area of interest before the start of the collaboration. Our explanation for this is that these projects probably aim to build up internal component competencies of the focal firm, hence bringing the internal R&D team up to speed in terms of R&D quality in a certain area is achieving a great innovation outcome for the focal firm. In case of having an integrated R&D team that mostly works with the BU, prior R&D team quality seems to be a must, potentially because these projects are already focusing more on actual smooth external technology transfer, which is hard to achieve when the receiving R&D team has no prior R&D quality.

Table 13 OLS models

| Model | Full model | | | Best model without residents | | | Best model with residents | | |
|---|---|---|---|---|---|---|---|---|---|
| | All direct and all interaction effects | | | Interaction BU direct, Quality * recombination; Quality * CTO | | | Recombination does not play a role; no direct relation with quality R&D team; BU & CTO interaction fully mediate | | |
| Project selection | All | No Residents | Residents | All | No Residents | Residents | All | No Residents | Residents |
| *Dependent variable* Innovation Outcome | | | | | | | | | |
| *Independent variables* | | | | | | | | | |
| Intercept | 1.4041* | 1.6171 | -4.7377** | 1.7373*** | 1.99*** | 1.784** | .6927 | 0.7014 | -5.1220** |
| | (.8292) | (1.076) | (2.0812) | (0.3827) | (0.428) | (0.7787) | (.4611) | (0.5134) | (1.9834) |
| Use of licensed technology | .2169* | .3556*** | 0.3002 | .2162** | 0.337*** | -.0212 | .2433** | .3561*** | .3619 |
| | (.1176) | (.1246) | (.3477) | (.1084) | (0.114) | (.2210) | (.1116) | (.1256) | (.2220) |
| Own R&D team | 1.0798** | .9050** | 7.989*** | 1.072** | 0.929** | 0.8464 | 1.1265*** | .9313** | 7.2164*** |
| | (.4257) | (.4557) | (2.1692) | (.4105) | (0.432) | (1.0198) | (.3968) | (.4499) | (1.9422) |
| Recombination | .2592 | .0774 | .1129 | | | | | | |
| | (.4450) | (.4710) | (.9942) | | | | | | |
| Interaction CTO | .2606 | .1359 | 3.0987*** | | | | .5446** | .4959* | 3.2670*** |
| | (.3612) | (.4616) | (.9219) | | | | (.2272) | (.2624) | (.8782) |
| Interaction BU | .4691 | .6125 | -1.5018* | .4571*** | 0.451** | 0.4850 | .7397*** | 1.0013*** | -.9877* |
| | (.3486) | (.4859) | (.7908) | (.1622) | (0.184) | (0.3276) | (.2056) | (.2512) | (.5530) |
| **H1:** Quality of internal R&D team (qual) | -.7347 | -.8286 | -1.5750 | -.8329*** | -1.303*** | -0.1121 | | | |
| | (.9504) | (1.185) | (1.7002) | (.3033) | (0.325) | (0.6985) | | | |
| **H2:** Residents | .2015*** | | 0.2401** | .1950*** | | 0.2364** | .1953*** | | .2247** |
| | (.0619) | | (.0885) | (.06052) | | (0.0994) | (.0611) | | (0.0842) |
| *Interaction terms* | | | | | | | | | |
| **H3:** Qual* Recombination | .1703 | .832 | -0.0531 | .4711** | 0.881*** | 0.1363 | | | |
| | (.5092) | (.5777) | (1.0495) | (.2424) | (0.314) | (0.3794)) | | | |
| Qual*CTO | .3398 | .3962 | -2.4597** | .5281*** | 0.565** | 0.4492 | .0763 | .0877 | -2.800*** |
| | (.4199) | (.5280) | (1.004) | .1831 | (0.214) | (0.4503) | (.1950) | (.2396) | (.9019) |
| Qual*BU | .0951 | -.2182 | 2.0538** | | | | -.1536 | -.4212** | 1.3976*** |
| | (.4138) | (.5576) | (.8531) | | | | (.1573) | (.1875) | (.4495) |
| N | 101 | 54 | 47 | 101 | 54 | 47 | 101 | 54 | 47 |
| Df | 10 | 9 | 10 | 7 | 9 | 7 | 7 | 6 | 7 |
| Adjusted $R^2$ | .3498 | .4396 | .3619 | .3585 | 0.473 | 0.1817 | .3785 | .4336 | .3961 |

*, **, *** indicate significance at 10%, 5% and 1% levels, respectively for two-tailed test.

Standard errors appear in parentheses.

To make interpretation of the results easier, we visualized parts of the best fitting model in case of collaborative R&D projects where there were no residents in place. In Figure 7 we show how IO varies with the interaction term between the internal quality of the R&D team with recombination and CTO/Research. In this best fitting model, the interaction effect with BU was significant, whereas the interaction with research team quality was not significant. Projects within a research organization usually involve new technology; hence, the internal R&D team with prior technical competencies will, in practice, often be a CTO/Research team and not a BU team. This might explain the lack of interaction between the quality of the R&D team and the BU team interaction. It appears that a high interaction and a recombination strategy are associated with a better innovation outcome; however, when the R&D team already has an established quality, and there is little interaction during the project with the R&D team and/or no recombination strategy, the innovation outcome suffers dramatically.

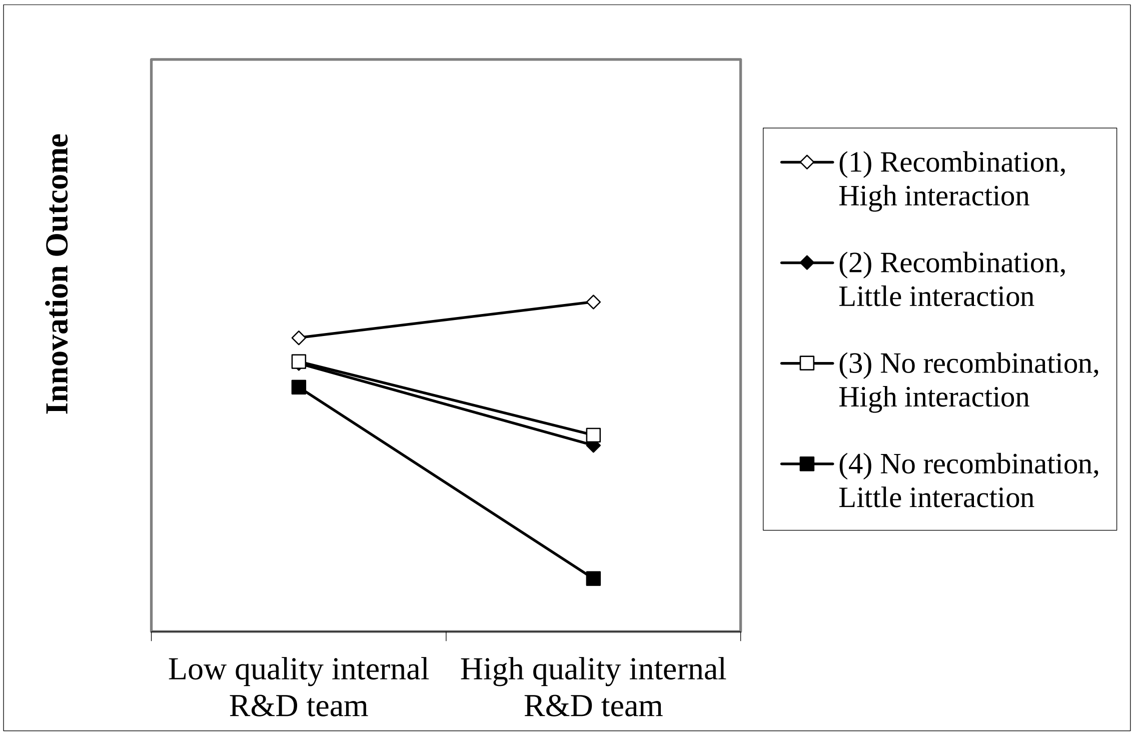


*Figure 7. Interaction effect of the quality of the internal R&D team, recombination and interaction with CTO/Research at one standard deviation above and below mean for R&D projects with no residents.*

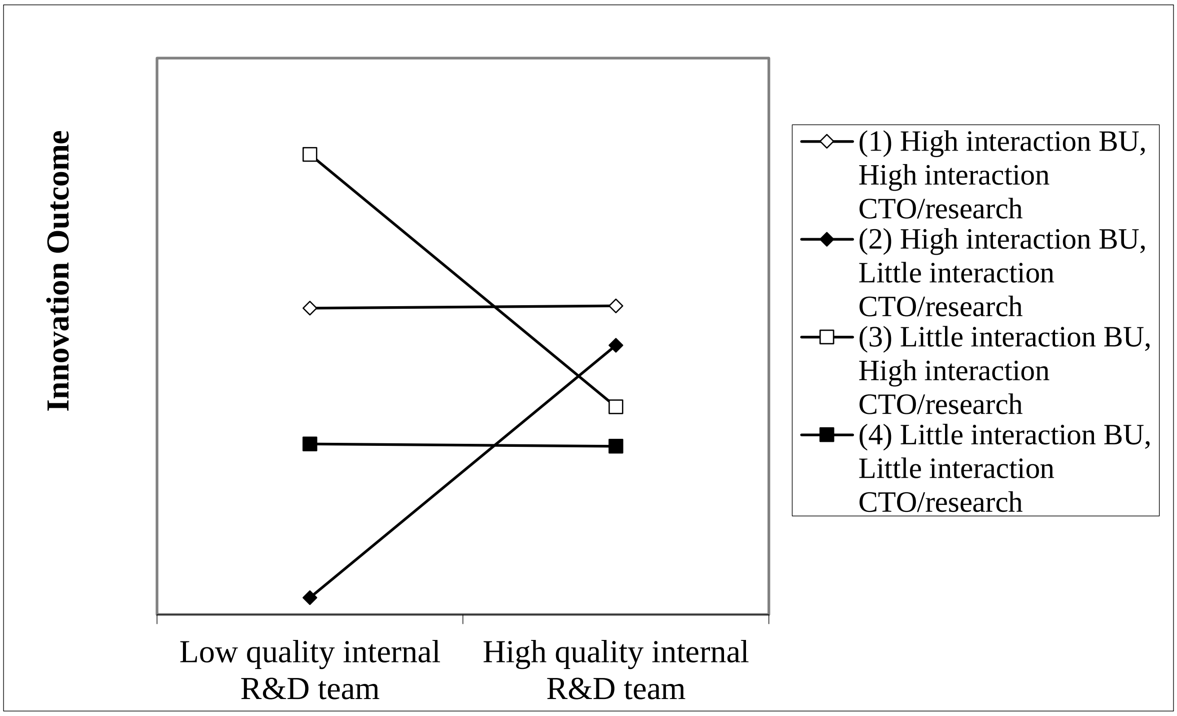


*Figure 8. Interaction effect of the quality of the internal R&D team, interaction with CTO/Research and interaction BU overall at one standard deviation above and below mean in case of an integrated research project.*

If there is an integrated R&D team, the effect differs widely, as shown in Figure 8 (based on the best fitting model with residents). As we only show the interaction terms, the actual value of innovation outcome cannot be compared; hence, the vertical axis is not shown on the same scale as in the previous Figure. The interaction Figure suggests that a high pre-project competence is useful only when there is high interaction with the BU and low interaction with the CTO/Research having a high-quality internal R&D team. We should be careful with this interpretation though, as it is easy to imagine that it is easier to obtain a large innovation outcome, in terms of increased technical knowhow within the company, when there are no component competencies in the field of interest internally. The post-project innovation step is always relatively smaller when there already was pre-project R&D quality in the field, even when the integrated R&D team is set up to reduce organizational, physical, and psychological boundaries. Another explanation could be that in the case of high interaction with the BU, the project was closer to the market. In Table 14 we summarize the hypothesis results.

*Table 14*
*Overview of Hypothesis Results*

| Nr. | Hypothesis | Result |
|---|---|---|
| H1 | Amongst external R&D collaborations with a research organization, an R&D team within the company with higher pre-project innovation quality is associated with a worse innovation outcome. | Support was found when there is no integrated R&D team. |
| H2 | Amongst external R&D collaborations with a research organization, an integrated R&D team delivers better innovation outcome. | Strong support was found. |
| H3 | Amongst external R&D collaborations with a research organization, the interaction effect of architectural competencies and pre-project innovation quality on the innovation outcome is positive. | Support was found when there is no integrated R&D team. |

**Robustness tests and other considerations**

Dividing the group into sub-groups with and without an integrated R&D team led to important new findings but also to a very small sample size of 54 projects without residents, resp 47 projects with residents in place.

For multilinear regression with a desired statistical power level of >80% and a probability level of 0.05%, the minimum sample size needed is achieved.(Abramowitz, 1965; J. Cohen, 1988; Soper, 2017). For our best fitting model 6 in the situation without residents, the sample size of 54 was sufficient to ensure the correct size of the coefficients with a probability level of 0.01. For the best model with residents, model 11, the sample size of 47 was sufficient to ensure the correct size of coefficients with a probability level of 0.05 but not with a probability level of 0.01. As long as the indicative sizes and sign of the coefficients are taken, rather than absolutes, there is no issue though.

It turns out that when dividing our group into sub-groups with and without an integrated R&D team, besides the number of residents being larger than zero or equal to zero, the means, as well as the standard deviations, varied significantly for a few variables that also turned out to be significant in the final models.

The first variable, overall evaluation, was the dependent variable, which had a mean of 4.14 and a standard deviation of 1.15 in case of residents while the overall evaluation had a mean of 3.40 and a standard deviation of 1.20 in case of no residents. The second and third independent variables that varied significantly were the interaction with CTO/research and interaction with BU. Interaction with CTO/research changed from 1.44 and a standard deviation of .66 in case of residents to a mean of .81 and a standard deviation of .77 in case of no residents while interaction with BU changed from 1.16 and a standard deviation of .80 in case of residents to a mean of 1.42 and a standard deviation of .77 in case of no residents. This could indicate that projects with an integrated R&D team, including residents, are often longer and involve mainly interaction with CTO/Research compared to projects without integrated R&D teams.

We investigated several variants of the described models to ensure robustness of the results, including standardizing non-binary variables. While the size of the coefficients sometimes changed, which also depended on the number of control variables included, the direction of statistically significant results remained similar. We also redid the best fitting models with robust regression, which also did not change the direction of statistically significant findings.

Another important assumption is that the projects were homogenous in their delivery, i.e., the transmitter side of knowledge transfer was assumed to behave similarly over all the projects investigated here. While this was only true up to a certain point, the delivery was more homogeneous than when the transmitter consisted of different research organizations or even different units within one research organization. Another important consideration is that as we only studied projects that actually took place. At least at some point before the start of the project, the responsible team at the company side thought that partnering with this research organization was the best choice for them in view of the alternatives at hand as well as in terms of technical performance, risk, time to market, budget, and resources available. Concerning the quality of the internal R&D team, the internal quality of Imec research differed across projects. We validated that for all projects used in the final sample, IP generation occurred in the same three-year period before the start of the project at Imec side; hence, Imec research teams achieved pre-project innovation quality in all cases. This was once more confirmed by the fact that the responsible management at the company side chose to collaborate with this particular research organization, which is a decision that they did not take lightly because of a significant cost and effort involved for the company. Thus, at least at the start of the project, the management of the company assessed the collaboration as the best option to generate and transfer the agreed upon knowledge to the company.

## Discussion

In a resource-based view, unique 'competencies' or 'capabilities' are known to be an important source of enduring strategic advantage. A vast amount of literature in the organization and resource science has identified that component or domain-specific competence is not enough when it comes to transfer and use of external knowledge (Cockburn & Henderson, 1998; Eisenhardt & Martin, 2000; Henderson & Cockburn, 1994; Williams & Lee, 2009). This paper focused on the build-up, transfer and use of external knowledge coming out of collaborative projects with a research organization as part of an open innovation environment and defined components of architectural competence, which play an important role in the successful transfer and use of external research results, more specifically closeness and breadth of interaction with the focal firm’s CTO/Research and BU/BL teams and the use of recombination. In developing our reasoning we noticed that earlier papers describing open innovation results found sometimes contradicting results in terms of component competencies and the success of knowledge transfer. For example Praest Knudsen and Bøtker Mortensen (2011) found that on immediate NPD performance measures the single firm strategy is performing better than the collaborative strategy. They also found that more open product development reduced the speed this development, which is in stark contrast to the original paradigm from (Chesbrough, 2006), which promises a faster way to get to the market by means of using external developments. Part of the literature highlighted the disadvantages by explaining that open innovation leads to more complex innovation processes, the ‘not invented here’ syndrome might lead to not benefiting optimally from external knowledge and unwanted spillovers can reduce the firms’ competitive advantage (Lazarotti & Manzini, 2009; Reed, Storrud‐Barnes, & Jessup, 2012). Vrande, P J De Jong, Vanhaverbeke, and De Rochemont (2009) specifically found that corporate organization and culture were the main challenges in open innovation for SME’s. They identified that main challenges for organizational competencies lie in the communication problems and alignment with partners as well as the lack of employee commitment (not-invented-here culture and professional pride) to practice open innovation.

In this paper, we have adopted exactly these challenges to become visible in our resource-based view where we have taken as starting point the behavioral view that most people don't welcome change and without special attention in the organization's culture and competencies a negative tendency towards external knowledge will prevail. We expanded the resource-based view of component competencies and architectural competencies, originally coined by (Henderson & Cockburn, 1994), by including interaction effects between architectural and component competencies. By validating this model, we added a more complete model to the resource-based theory, which explains both negative as well as positive results of previous studies on open innovation performance (Burcharth et al., 2014; Praest Knudsen & Bøtker Mortensen, 2011). The model, for R&D projects without an integrated R&D team is given in Figure 9.

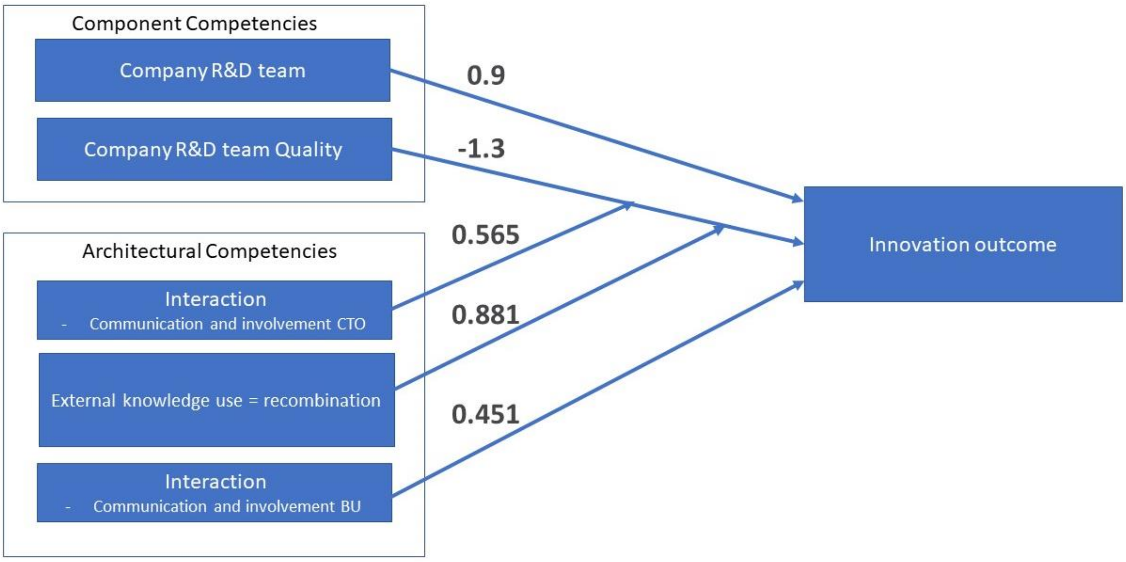


*Figure 9 Best fitting model found in this study for R&D projects without integrated R&D team.*

The updated model sheds light on the puzzling situation that a higher component competence sometimes hinders knowledge transfer instead of aiding it. As far as the authors are aware, this is the first paper which makes it explicit that high component competencies without similar high architectural competencies might hinder external knowledge transfer more than it helps. Like earlier papers, we found evidence that more widespread communication and interaction with the company's personnel leads to a better transfer. In our case, we showed that a wider interaction of CTO/Research and or Business line leads to more successful transfer and use of the research results from a research organization into NPD of the focal firm when executing a collaborative project without integrated R&D team. Previously, architectural competencies were often not separated from component competence. Mastering the architectural competence of recombination is advantageous, as it facilitates collaboration with external research partners from a distance and optimizes the knowledge transfer and use of the results from such an external partnership.

Strong and widespread interaction between the firm and research partner as well as the internal capacity to do recombination are the most important drivers of a positive innovation result when an internal R&D team is in place. Because we measured the external knowledge usage as seen from the research partner, we overcame an important limitation of earlier studies in which managers of the companies were asked to give their opinion on the external knowledge usage of the company. It is known that the intention of management and the actual implementation often diverge. This study showed what actually happened in terms of integrating the external knowledge rather than the intention of management to achieve recombination, which might in fact not have been applied in practice.

An important finding of this study is that having a higher component competence is not always helpful in getting more out of external research collaborations without an integrated R&D team. Only high architectural competence leads to fast and effective knowledge transfer. High component competence combined with a low architectural competence might lead to worse results, as in some cases, the company's team, possibly driven by NIH attitudes, including professional pride or unwillingness to change, will show itself unwilling to invest deeply in parameters, which help knowledge transfer. Worse, the team might even explicitly start working against the collaboration in an attempt to show that their internal ways and thinking are more superior compared to those of an outsider.

Co-location of R&D teams has been given ample attention in literature and the general finding is that the positive effects of co-location prevail especially to get to a shorter development time, while it does not affect quality of the final development that much (Eccles, Smith, Tanner, Van Belle, & Van Der Watt, 2010; Mendonça Natalino Zenun, Loureiro, & de Araujo Junior, 2007). In the literature so far limited attention has been given to the analysis of integrated R&D teams in the context of open innovation, where residents from the focal firm reside together with the research team where the focal firm intends to use and transfer external knowledge from. This is a pity as (Hippel, 1998) already found that co-location is important to transfer "sticky" intacit knowledge. (Eccles et al., 2010; Hippel, 1998; Mendonça Natalino Zenun et al., 2007)

The best fitting model in case of an integrated research team is shown in Figure 10.

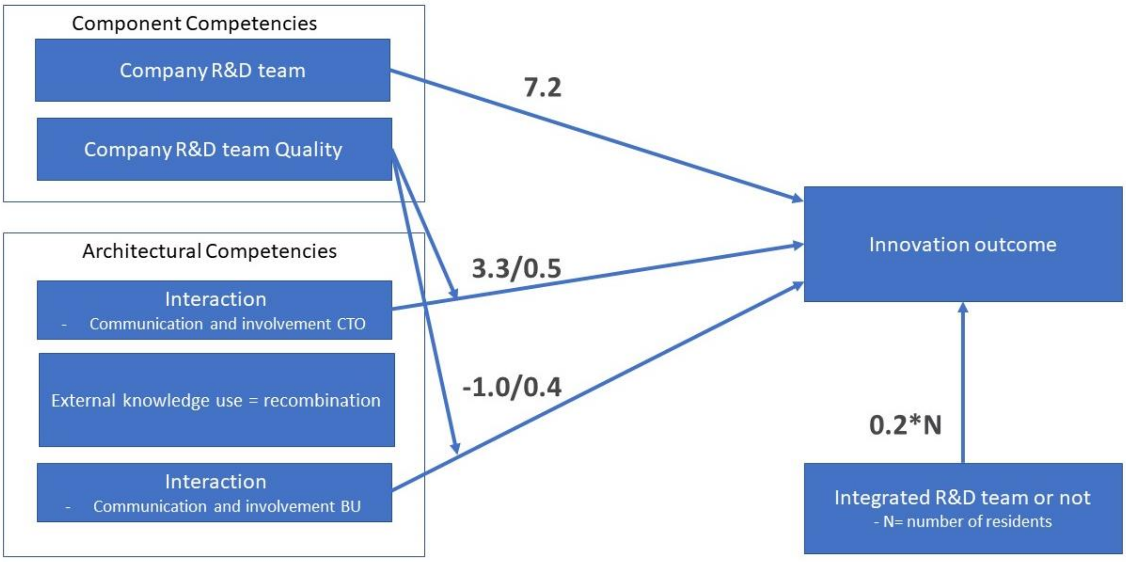


*Figure 10 Best fitting model found in this study for R&D projects with integrated R&D team. (x without/x with prior R&D team quality)*

The results from our study indicate that reducing barriers for tacit knowledge transfer as well as organizational, psychological and physical barriers by forming an integrated R&D team strongly improves the chances of success and the innovation outcome, but mainly during an earlier phase of the research project when BU involvement is not needed yet or limited. The positive effect of an integrated R&D team is further increased when the pre-project innovation quality of the R&D team is low; hence, a preliminary conclusion could be that residents are especially helpful when the project's aim is to build up new competencies for the company outside its current R&D domains. In this case, the NIH effect is not present, and the R&D team will probably welcome the results, leading to high knowledge transfer. To our surprise, we noticed that in the case of an integrated R&D team, a more widespread interaction with the BU can actually be negative in case of a low competence pre-project innovation team. The insight that these integrated R&D projects are done usually earlier in the innovation pipeline and hence would benefit from involving a Research team from CTO rather than a BU development team could explain this result. Indeed, the members of a research team from CTO/research with pre-existing competencies might be severely bothered and feel as if they are not adequate themselves if the BU starts to interact strongly with an outside research partner in the same field instead of going via the research team within the CTO/research organization of the focal firm. It would involve more detailed investigations from an organizational psychology point of view to understand this mechanism better.

An integrated R&D team delivers additional benefits, it can (partly) compensate for lower architectural competencies but it is difficult, costly and involves sending multiple residents. Investing in building higher architectural competencies within the firm remains the best advice in the long-term. However, the authors believe that being part of integrated R&D teams can actually help increase the architectural competencies of the focal firm in the long-term. Over time the communication and knowledge transfer and use mechanisms present in within the focal firm will improve from the learnings of working closely with an external research organization. Here, the longitudinal effect of working with integrated R&D teams is not fully understood, and it would be an interesting topic of further study to expand and complete the theoretical model on these aspects.

Despite all risks associated with self-reporting, this study suggests that self-reported success of an R&D collaboration, defined from the perspective of the industrial partner, is highly correlated with factual measurements, such as the use of research results within research and/or product development of the focal firm and the increase of patent (applications) at the focal firm in the area of the collaboration during and after the project. We ensured under-reporting of successful elements of knowledge transfer here rather than over-reporting; hence, we can be quite confident that even though the explanatory power of the model was rather low (12%), the relationship with the success was significant, as indicated by the business and technical officers of the R&D Centre side. Research organization can be seen as a bridge between universities and industry in that they help to transform research results into easier to integrate product results. And as shown in this study, they can also help to build-up internal technical competencies at the focal firm. As such, research organizations are knowledge brokers when knowledge distance is medium to high. We believe that a successful innovation outcome is hence an indirect indication of increased R&D performance at the side of the focal firm.

Finally, our study supports the importance of organization decisions. We showed that when integrated R&D teams are being formed, the competence of recombination ceases to be important. Future research could look further into the decision aspects involved, but a preliminary theory could be that managers who expect their team to score lower on architectural competencies can improve the chances of success by spending efforts on an integrated R&D team, i.e., sending residents to reduce contextual, spatial, and organizational boundaries, especially when they want to build up component competencies, which are not present within the existing R&D teams.

## Limitations and future research

This study had a limitation in the sense that it was investigating a unique but heavily self-selected group of research collaborations. Thus, self-selection bias and unobserved variables could be potential problems. Indeed, the fact that the partner decides to work with Imec is an explicit decision, which could end the search and negotiation process both from the company's side as well as from Imec's side. Instead of partnering with Imec, the company could have decided to partner with another research organization or, in selected cases, with a university or have alternatively decided to do the research in-house. In the case of further development rather than more basic research, working with a supplier might also be an option, though the results of this kind of partnership differ greatly from the results of research collaboration. Hence, we think it is fair to assume that in most cases, only internal research or working with another research organization was the alternative for this set of projects. The fact that the company partners with Imec in itself means that the company has an active policy of outsourcing at least part of their research activities. While we could not correct for the mechanism of complete internal research, we could correct for having an own research team in the field of interest (and hence doing part of the R&D internally) as well as for the research quality of the internal team (by means of their patent applications in the field of interest). As this was the first study, the quality of the internal team at the start of the project was still very coarsely evaluated as a binary, i.e., existing or non-existing, and of course, this could be refined in the future. Please note that in view of the average size of the research project in terms of resources and/or investments, only a few universities can be viewed as an alternative. Many projects cannot be executed by smaller university groups due to staffing and processing costs, as they usually have project teams of four people or less and limited infrastructure available. The success rate in assimilation and use of this external research knowledge back into the company also says nothing about the comparison with the success of the alternative, which would be to do the work internally.

However, assuming that managers make decisions bearing the best intentions of the firm in mind, it is fair to assume that these collaborations have started with the faith of the management of the company that this relationship will bring their company advantages in terms of decreased R&D costs, risk, and time to market or increased performance of their products or services. What we did not measure is how the internal company's R&D team felt about the collaboration and this is an important avenue for future research. The company's team, possibly driven by NIH attitudes, including professional pride or unwillingness to change, could show itself unwilling to invest deeply in parameters, which help knowledge transfer. Worse, the team might even explicitly start working against the collaboration in certain cases in an attempt to show that their internal ways and thinking are more superior compared to those of an outsider.

In this study, we look only at the success of the knowledge transfer. We did not measure the effect of this transfer on the new product or service or the importance of the partnership in differentiating the final product in terms of features, time to market, and costs. Another limitation is that the study focused only on what the company can do in view of an existing set of competencies and routines at the research organization side of one particular research organization, namely Imec. It would certainly be of interest to see whether the results can be repeated on datasets from other research organizations, which might reveal other interfirm behavior towards the companies. This is one direction for future research.

Another limitation is the fact that this study investigated only the barriers in knowledge transfer at the receiver's side of things, assuming that the transmitter, in this case, the research organization, shows similar or at least similar enough behavior over different research projects and research partners. It would be interesting to further study also the most effective transmitter behavior and the interaction between transmitter and receiver behavior.

Residents, who are a part of integrated R&D teams, have been proven to effectively increase the successful transfer of external knowledge to build up internal component competencies. However, managers of companies perceive spill-over via the research organization into competitors' products as a strong risk. The second direction of future research could try to uncover insights into the size of the threat and the costs of that aspect as well as further uncover the mechanisms behind manager's decisions to build an integrated R&D team, i.e., sending residents to sit physically at the research organization, or withholding that.

A third limitation of our approach is that we had only a very rough indication of the quality of the R&D team at the beginning of the project. Future research should focus on developing a more detailed scale to assess the quality of the R&D team at the start of a collaborative project as well as on expanding the number of projects.

## Managerial implications

The managerial implications of this study are abundant, and they give some clear directions on measures that can be taken to improve the chances of successful knowledge transfer out of an external research partnership. As part of the prior evaluation of a potential research effort, it would be good for managers to evaluate their organizational competencies, not only their component competencies but also their architectural competencies, beforehand. Special attention should be given to a "not invented here" attitude in key individuals of the company's R&D team, especially when component competence is already high in this field. In that case, company researchers should have the same objectives and should be rewarded for successful research collaboration instead of company researchers trying to prove that they can do better compared to the external research organization. The formation of an integrated R&D team, either on-site with residents or multi-site as virtual integrated R&D team, is helpful as well. Furthermore, managers should truthfully look into the external knowledge usage skills that their R&D teams possess. If the R&D team is not proficient in recombination, it can learn from external research efforts by integrating the research teams, of course at the cost of potential spill-overs to the research organization and, via that route, to potential competitors.

*Table 15*
*Managerial Implications When Judging Organizational Absorptive Competencies in the Component and Architectural Dimension Prior to an External Research Collaboration*

| Organizational competencies | Low architectural competence | High Architectural competence |
|---|---|---|
| Low component competence | It will be difficult or impossible to successfully assimilate and integrate external R&D results into the NPD. Manager can stimulate component competence build-up by creating an integrated R&D team and can start to create communication structures within the company to disseminate new knowledge more widely (start of building up architectural competencies). | External research can be used to speed up internal component competence development, i.e., the assimilation of the research results, both explicit as well as tacit, will go speedily if the efforts are made, use in NPD follows only after assimilation completed. Having or creating an own R&D team in parallel with the external research efforts is an important factor to make sure that the new knowledge gets embedded within the organization for the future. |
| High component competence | Negative attitudes and limited architectural competencies can significantly hinder the transfer of external R&D results in NPD; especially transfer of tacit knowledge and knowhow. Remedy is truly integrating the external research activity with your internal research activity. Make sure that the company's R&D team has objectives and incentives, which stimulate successful transfer out of the research collaboration. For the longer term, start to make the necessary changes within your company's organization structure, culture, and communication to increase architectural competencies over time. Especially measures and rewards that force much more external thinking are useful. | When a company has both a competent own R&D team as well as high architectural competence and capability to spread new knowledge within the organization fast and recombine external knowledge with internal knowledge, True Co-creation becomes possible. Assimilation takes almost no time because of high component competence. Fast and widespread use of external R&D results in NPD takes shorter time to market and reduces development cost. The own R&D team can spend more time on making better and more unique product differentiators and recombine the best innovations from outside as well as inside the company. It is important for a manager to avoid considering only internal aspects. It is important to reward external collaboration and to reduce any psychological, organizational, and physical boundaries to collaboration. |

## Conclusions

Close collaboration matters! In this study, we showed that lowering barriers to collaboration in terms of communication, technical closeness, physical closeness, and psychological closeness all help to increase the innovation outcome of an external research project with a research partner. As shown in many earlier research papers, having higher architectural competencies is a significant and enduring competitive advantage for a company. However, where previous papers found puzzling and sometimes contradictory results in terms of component competencies, this paper unraveled a few different factors that can help explain these contradictory findings. In this paper, we developed an integral resource-based model, which combines architectural and component competencies and shows the interactions quantitatively rather than qualitatively. The current study indicated that having higher pre-project innovation quality reduces the innovation outcome, making external collaborations less useful for an experienced innovation team, unless their architectural competencies are at the same high level. It is, as far as the authors are aware, the first study to show that two specific drivers of architectural competence, i.e., recombination and more frequent and more breadth of interaction, mediate component competencies. It also shows that integrated R&D teams can help to be more effective in external knowledge transfer and use. Previous studies (Collins & Hitt, 2006; Martin & Salomon, 2003; Martin, Salomon, & Wu, 2010) have already shown that due to its nature, tacit knowledge has a higher potential to create a distinctive competitive position compared to explicit knowledge; hence, integrated R&D teams can greatly reduce the barrier of tacit knowledge transfer. This study adds to these studies by showing that integrated R&D teams also decrease explicit knowledge transfer barriers. Firms that recognize the challenge in effective knowledge transfer should develop organizational competencies but also organizational practices to benefit from external knowledge. In this manner, this paper also provides some insights for the practicing manager.

## Acknowledgments

The author thanks the executive management of Imec for supporting this research and providing access to unique sources of data from completed projects. I also thank the program, business and account management of the Imec SE organization for contributing with their insights and evaluations of past projects without which this study would have never been possible. Kathleen de Belder and the Imec IP department were indispensable in building our understanding of the meaning of patents in this area and adding the relevant IP classes to different research areas. Finally, I thank Vilma Sharma who contributed to this project as a research assistant.

**Appendix 1: Imec project database: additional data collected**

| Use of Developed technology | |
|---|---|
| 0 | Unclear if used at all |
| 1 | Only take-up in research |
| 2 | Use in product development within 3 yrs after start of collaborative R&D |
| 3 | Use in product development within 1 year after start of collaborative R&D |

| Own R&D team | |
|---|---|
| 0 | There was no focal firm R&D team at the beginning of the project |
| 1 | There was a focal firm R&D team at the beginning of the project |

| Internal R&D quality, scale 0-5 likert | |
|---|---|
| 0 | No knowledge |
| … | |
| … | |
| 5 | World class in this area |

Quantitative addition to the database has been made by the actual number of patents and patent disclosures in the relevant field(s), in the years before, during and after the project

| Internal R&D quantity | |
|---|---|
| 0 | No internal R&D on this topic |
| 1 | Small R&D team on this topic (<5 people) |
| 2 | Core R&D team available on this topic (<15 people) |
| 3 | Significant R&D team(s) available on this topic (<50 people) |
| 4 | Large R&D mass in this area (outnumbering Imec's team) |

| Interaction with technical team of focal firm | |
|---|---|
| 0 | Only partner days; plus maximum 2 other visits per year |
| 1 | Monthly technical meetings, workshop maximum 4 times a year |
| 2 | More frequent than every month technical follow-up. Frequent technical follow-up including residents or other forms of close collaboration |
| 3 | Common design database |

| External Knowledge Use Strategy | |
|---|---|
| 0 | Don’t know |
| 1 | Adapt Imec input to fit in their architecture, with their interfaces etc. or have Imec deliver a special version which fits in their system without further adaptations |
| 2 | adapt their own architecture, interfaces etc to be able to use Imec’s input; or use Imec’s technology as much as possible without changing it |
| 3 | Adapt both their own as well as Imec results heavily to create a new system |

| Involvement BU/BL | |
|---|---|
| 0 | No involvement BU/BL |
| 1 | Some involvement BU/BL |
| 2 | We mainly worked with BU/BL |

| Involvement CTO/Research | |
|---|---|
| 0 | No involvement CTO/Research |
| 1 | Some involvement CTO/Research |
| 2 | We mainly worked with CTO/Research |

| Residents | |
|---|---|
| N | Fill in the number of residents involved from focal firm |

| Overall evaluation, Likert 1-5 | |
|---|---|
| 1…5 | How successful was this project for the focal firm in terms of IP generation, knowledge transfer to and knowledge use by the focal firm? This was evaluated by the program director, business development manager and/or program/project manager responsible. 1= unsuccessful, 5= highly successful |

The validity of this variable was checked by linear regression of results used and patent application increase at focal firm.

Also the different independent evaluators never had more than 1 point difference in their evaluation, showing a good coherence in answers., >75% evaluators had the same answer so inter-rater reliability is high.

## Appendix 2: Detailed OLS results

*The Best Fitting Models are 6 and 10 in Case of Not Having Versus Having an integrated R&D*

| Model | 1 | | | 2A **residents in numbers** | 2B **Residents dummy** | 2C **Residents dummy & number** | 3 **(residents in numbers)** | |
|---|---|---|---|---|---|---|---|---|
| | Direct effects only | Architectural competence variables | Plus prepr. internal R&D team quality | Integrated R&D team **H2+** | ~10.7% ~~10.2% | | | |
| Project selection | All | All | All | All | All | All | No Residents | Residents |
| *Dependent variable* Innovation Outcome | | | | | | | | |
| *Independent variables* | | | | | | | | |
| Intercept | 0.810* | 0.921* | 0.960* | 1.003** | 1.046** | 0.960* | 1.525** | 0.073 |
| | (0.482) | (0.511) | (0.513) | (0.487) | (0.512) | (0.491) | (0.565) | (1.058) |
| Use of licensed | 0.214** | 0.255** | 0.3273** | 0.233** | 0.251** | 0.238** | 0.345*** | 0.110 |
| technology | (0.406) | (0.111) | (0.113) | (0.107) | (0.113) | (0.108) | (0.121) | (0.224) |
| Own R&D team | 1.099*** | 1.175*** | 1.239** | 1.078** | 1.144*** | 1.103*** | 0.676^^ | 1.504% |
| | (0.406) | (0.424) | (0.430) | (0.410) | (0.430) | (0.412) | (0.450) | (0.892) |
| Recombination | | 0.332 | 0.355 | 0.395* | 0.3671~ | 0.396* | 0.589** | 0.070 |
| | | (0.225) | (0.227) | (0.215) | (0.225) | (0.216) | (0.279) | (0.347) |
| Interaction | 0.568*** | 0.536*** | 0.561** | 0.515*** | 0.459** | 0.567*** | 0.394** | 0.776** |
| CTO H**2+** | (0.169) | (0.182) | (0.184) | (0.175) | (0.193) | (0.188) | (0.213) | (0.389) |
| Interaction BU | 0.627*** | 0.549*** | 0.539** | 0.543*** | 0.520*** | 0.566*** | 0.555** | 0.580** |
| | (0.175) | (0.188) | (0.189) | (0.179) | (0.187) | (0.180) | (0.234) | (0.285) |
| Quality of internal | | | -0.210 | -0.211 | -0.190 | -0.224 | -.0525** | 0.0753 |
| R&D team (qual) **H1-** | | | (0.229) | (0.213) | (0.223) | (0.214) | (0.249) | (0.449) |
| Residents | 0.200*** | | | 0.206*** | D:0.3472 ~~ | D:-0.207 | | 0.264*** |
| **H2+** | (0.060) | | | (0.060) | (0.211) | (0.272)<br>0.248***<br>(0.081) | | (0.0943) |
| *Interaction terms* **H3+** | | | | | | | | |
| Qual* Recombination | | | | | | | | |
| Qual*CTO | | | | | | | | |
| Qual*BU | | | | | | | | |
| N | 101 | 101 | 101 | 101 | 101 | 101 | 54 | 47 |
| Df | 5 | 5 | 6 | 7 | 7 | 8 | 6 | 7 |
| Adjusted $R^2$ | 0.350 | 0.292 | 0.291 | 0.363 | 0.303 | 0.360 | 0.417 | 0.239 |
| F | 11.74 | 5.98 | 7.83 | 9.14 | 7.22 | 8.04 | 7.32 | 3.06 |

OLS estimation, *, **, *** indicate significance at 10%, 5% and 1% levels, respectively, for two-tailed test. Standard errors appear in parentheses.

| Model | 4a | | | 4b | | | 5 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Quality direct, Quality*CTO ~~=10.2% | | | Quality direct, Quality*BU | | | Quality direct and quality*recombination ~11.1% | | |
| Project selection | All | No Residents | Residents | All | No Residents $=10.4% | Residents | All | No Residents | Residents |
| *Dependent variable* Innovation Outcome | | | | | | | | | |
| *Indep. variables* | | | | | | | | | |
| Intercept | 1.239** (0.536) | 1.828*** (0.584) | -3.656*** (2.129) | 0.886 (0.549) | 1.012 (0.712) | -0.358 (1.138) | 1.032** (0.494) | 1.659*** (0.569) | 0.070 (1.175) |
| Use of licensed technology | 1.043** (0.412) | 0.357** (0.119) | 0.362 (0.248) | 0.247** (0.112) | 0.382*** (0.124) | 0.0223 (0.221) | 0.227** (0.109) | 0.329*** (0.120) | 0.112 (0.229) |
| Own R&D team | 1.043** (0.412) | 0.855** (0.454) | 4.104** (1.528) | 1.038** (0.421) | 0.754$ (0.453) | 4.492** (1.729) | 1.098*** (0.414) | 0.728~ (0.447) | 1.501 (0.907) |
| Recombination | 0.384* 0.215 | 0.629** (0.274) | 0.097 (0.334) | 0.400** (0.216) | 0.607** (0.278) | 0.040 (0.335) | 0.232 (0.437) | 0.100 (0.455) | 0.117 (1.088) |
| Interaction CTO | 0.313 (0.174) | 0.008 (0.311) | 2.533** (0.933) | 0.518*** (0.176) | 0.431* (0.214) | 1.029** (0.396) | 0.513** (0.176) | 0.393** (0.211) | 0.777* (0.394) |
| Interaction BU | 0.540*** (0.179) | 0.468** (0.236) | 0.263 (0.314) | 0.637** (0.269) | 0.820** (0.324) | -0.889 (0.787) | 0.541** (0.180) | 0.535** (0.287) | 0.580* (0.229) |
| Quality of internal R&D team (qual) **H1-** | -0.496 (0.365) | -0.724** (0.287) | 1.861** (0.970) | -0.028 (0.447) | 0.030 (0.533) | -3.107** (1.656) | -.259 (0.251) | -0.724** (0.287) | 0.0807 (0.471) |
| Residents **H2+** | 0.202*** (0.060) | | 0.229** (0.092) | 0.203*** (0.061) | | 0.287*** (0.091) | 0.203*** (0.061) | | 0.265*** (0.096) |
| *Interaction terms* **H3+** | | | | | | | | | |
| Qual* Recombination | | | | | | | 0.213 (0.494) | 0.739 (0.547) | -0.0514 (1.143) |
| Qual*CTO | 0.274 (0.286) | 0.550~~ (0.330) | -2.131** (1.037) | | | | | | |
| Qual*BU | | | | -0.131 (0.280) | -0.404 (0.343) | 1.759** (0.883) | | | |
| N | 101 | 54 | 47 | 101 | 54 | 47 | 101 | 54 | 47 |
| Df | 8 | 7 | 8 | 8 | 7 | 8 | 7 | 7 | 8 |
| Adjusted $R^2$ | 0.363 | 0.439 | 0.297 | 0.358 | 0.422 | 0.292 | 0.357 | 0.427 | 0.219 |
| F | 8.11 | 6.91 | 3.43 | 7.95 | 6.53 | 3.38 | 7.95 | 6.65 | |

| Model | 6 | | | 7 FULL MODEL | | |
|---|---|---|---|---|---|---|
| | Interaction BU direct, Quality * recombination; Quality * CTO | | | All direct and all interaction effects | | |
| Project selection | All | No Residents | Residents | All | No residents | Residents |
| *Dependent variable* Innovation Outcome | | | | | | |
| *Independent variables* | | | | | | |
| Intercept | 1.737*** (0.3827) | 1.99*** (0.428) | 1.784** (0.7787) | 1.4041* (.8292) | 1.6171 (1.076) | -4.7377** (2.0812) |
| Use of licensed technology | .2162** (.1084) | 0.337*** (0.114) | -.0212 (.2210) | .2169* (.1176) | .3556*** (.1246) | 0.3002 (.3477) |
| Own R&D team | 1.072** (.4105) | 0.929** (0.432) | 0.8464 (1.0198) | 1.0798** (.4257) | .9050** (.4557) | 7.989*** (2.1692) |
| Recombination | | | | .2592 (.4450) | .0774 (.4710) | .1129 (.9942) |
| Interaction CTO | | | | .2606 (.3612) | .1359 (.4616) | 3.0987*** (.9219) |
| Interaction BU | .4571*** (.1622) | 0.451** (0.184) | 0.4850 (0.3276) | .4691 (.3486) | .6125 (.4859) | -1.5018* (.7908) |
| Quality of internal R&D team (qual) **H1-** | -.833*** (.3033) | -1.303*** (0.325) | -0.1121 (0.6985) | -.7347 (.9504) | -.8286 (1.185) | -1.5750 (1.7002) |
| Residents **H2+** | .1950*** (.06052) | | 0.2364** (0.0994) | .2015*** (.0619) | | 0.2401** (.0885) |
| *Interaction terms* **H3+** | | | | | | |
| Qual* Recombination | .4711** (.2424) | 0.881*** (0.314) | 0.1363 (0.3794)) | .1703 (.5092) | .832 (.5777) | -0.0531 (1.0495) |
| Qual*CTO | .5281*** .1831 | 0.565** (0.214) | 0.4492 (0.4503) | .3398 (.4199) | .3962 (.5280) | -2.4597** (1.004) |
| Qual*BU | | | | .0951 (.4138) | -.2182 (.5576) | 2.0538** (.8531) |
| N | 101 | 54 | 47 | 101 | 54 | 47 |
| Df | 7 | 9 | 7 | 10 | 9 | 10 |
| Adjusted $R^2$ | .3585 | 0.473 | 0.1817 | .3498 | .4396 | .3619 |
| F | 8.98 | 8.91 | 2.46 | 6.83 | 5.62 | 3.61 |

| | 8 | | | 9 | | | 10 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Quality direct, Quality interacts BU & CTO | | | BU & CTO as full mediator for quality R&D team | | | Recombination does not play a role; no direct relation with quality R&D team; BU & CTO interaction fully mediate | | |
| Project selection | All | No Residents | Residents | All | No residents | Residents | All | No Residents | Residents ~=11.0% |
| *Dependent variable* Innovation Outcome | | | | | | | | | |
| *Independent variables* | | | | | | | | | |
| Intercept | 1.4384* | 1.9334* | -4.744** | .9002* | 1.0174* | -5.0943** | .6927 | 0.789 | -5.122** |
| | (.8220) | (1.066) | (2.0495) | (.5005) | (.5578) | (2.0121) | (.4611) | (0.571) | (1.9834) |
| Use of licensed | .2183* | .3528*** | .3001 | .2477** | .3833*** | .3597 | .2433** | .3561*** | .363~ |
| technology | (.1169) | (.1261) | (.2344) | (0.1110) | (.1224) | (.2253) | (.1116) | (.1256) | (.2220) |
| Own R&D | 1.070** | .8586* | 7.992*** | 1.0028** | .8041* | 7.2082*** | 1.127*** | .881* | 7.2164*** |
| team | (.4226) | (.4600) | (2.1394) | (.4136) | (.4568) | (1.9668) | (.3968) | (.474) | (1.9422) |
| Recom. | .3889* | .6291** | 0.0653 | .3966* | .6190** | .0687 | | | |
| | (.2168) | (.2775) | (.3140) | (.2162) | (.2773) | (0.3135) | | | |
| Interaction | .2434 | -.0307 | 3.1020*** | .4614* | .3383 | 3.2546*** | .5446** | .479* | 3.2670*** |
| CTO | .3558 | (.4522) | (0.9070) | (.2327) | (.2658) | (.8909) | (.2272) | (.269) | (.8782) |
| Interaction BU | .4499 | .4196 | -1.4981* | .6701*** | .8188*** | -.9944* | .7397*** | 0.985*** | -.9877* |
| | (.3422) | (.4726) | (.7767) | (.2077) | (.2581) | (.5607) | (.2056) | (.257) | (.5530) |
| Quality of | -.7637 | -1.1831 | -1.5665 | | | | | | |
| internal R&D | (.9418) | (1.1734) | (1.6690) | | | | | | |
| team (qual) **H1-** | | | | | | | | | |
| Residents | .2043*** | | .2397*** | .2010*** | | .2254** | .1953*** | | .2247** |
| **H2+** | (.0610) | | (.0868) | (.0608) | | (.0853) | (.0611) | | (0.0842) |
| *Interaction terms* | | | | | | | | | |
| **H3+** | | | | | | | | | |
| Qual* Recombination | | | | | | | | | |
| Qual*CTO | .3649 | .5972 | -2.4655** | .0715 | .1338 | -2.8059*** | .0763 | .091 | -2.800*** |
| | (.4111) | (.5153) | (.9842) | (.1950) | (.2331) | (.9135) | (.1950) | (.242) | (.9019) |
| Qual*BU | .1243 | .0625 | 2.0487** | -.1762 | -.4379** | 1.3918*** | -.1536 | -.418** | 1.3976*** |
| | (.4024) | (.5287) | (0.8357) | (.1565) | (.1821) | (.4558) | (.1573) | (.189) | (.4495) |
| N | 101 | 54 | 47 | 101 | 54 | 47 | 101 | 54 | 47 |
| Df | 9 | 8 | 9 | 8 | 7 | 8 | 7 | 6 | 7 |
| Adjusted $R^2$ | .3562 | .4262 | .3791 | .3586 | .4260 | .3810 | .3785 | .377 | .3961 |
| F | 7.15 | 5.92 | 4.12 | 7.99 | 6.62 | 4.54 | 9.79 | 6.35 | 5.31 |

# Chapter 4
# Fill up the knowledge gap or build a bridge:
# Knowledge distance and absorptive capacity


## Abstract

Companies rely on external partners to engage in complex and risky R&D. The literature nowadays largely assumes that internal technical competencies and absorptive capacity are complementary skills that are both needed to select adequate partners as well as deliver the best possible new product development (NPD) performance. In this study, we argue that these skills might be influencing NPD performance in a much more independent manner. We first conceptualize the idea that partner selection and R&D project aims depend on the perceived knowledge distance that the focal firm sees itself confronted it. The aim of the R&D project, being to develop a product to market or pre-product development is decided prior to project start and usually in line with a clearly gated innovation process. We theorize that the decision to start full product development is only taken when the decision takers deem the technical risks to be low enough. As long as perceived knowledge distance is high, a focal firm either does pre-product development with a R&D partner to build up their own component competencies or does pre-product development with the aim to have a reliable partner that can bridge the perceived knowledge distance and that the result can be integrated in the focal firm's product. We use a sample of 111 completed R&D projects in the semiconductor industry to examine the relation between the goal to develop a product to market and its related new product development performance and the absorptive capacity and knowledge distance of the focal firm. Surprisingly, we find that when an R&D project leads to a product on the market, the new product development performance is mainly dependent on absorptive capacity and not much on knowledge distance anymore. These results indicate that internal technical competencies and absorptive capacity bridge knowledge distance in different manners and more independent than previously thought. Internal technical competencies reduce knowledge distance while absorptive capacity can overcome a remaining knowledge distance by being capable to bridge the gap with one or more R&D partner(s). We propose an updated model to explain this.



*Keywords*: absorptive capacity, knowledge distance, new product development, organizational competencies, partner selection, alliances, R&D

## Introduction

Firms that conduct expensive, risky, and/or complex development rely on partnerships with external sources of expertise to maintain their innovation performance (Cassiman & Veugelers, 2002; Morgan & Berthon, 2008). Such partnership and alliance-forming behavior have been well-documented in pharmaceutical, information technology, and semiconductor industries (Gomes-Casseres, 1997, 2003; Miotti & Sachwald, 2003; Shan, Walker, & Kogut, 1994). Cohen and Levinthal (Cooper, 1994) and others have noted that firms wishing to take advantage of research conducted outside the firm's boundaries need to invest in "absorptive capacity" to accumulate the knowledge, skills, and organizational competencies necessary to identify, assimilate, transform, and exploit external knowledge. Absorptive capacity goes much further than simply conducting a certain amount of research in-house to be able to transfer external knowledge into the company. Separately, we define knowledge distance as the extent to which the new knowledge or technology which is needed for the new product under development differs from the component competence-base or R&D capacity of the focal firm. In the literature knowledge distance has been coupled to search of external technology (Levinthal & March, 1993; March, 1991) and the selection of partners (Levinthal & March, 1993; March, 1991). Several studies have defined absorptive capacity as directly related to having internal R&D capacity and the kind of technical competencies that are available within the focal firm (Dyer & Singh, 1998; Murovec & Prodan, 2009; Rosenberg, 1990), while others suggest that radical innovation is more related to knowledge sharing capability and exploitative learning than to the diversity of the internal knowledge base (Maes & Sels, 2014) much less dependent on internal R&D capacity. In this paper, we join the line of thinking that more radical innovation, in terms of introducing new technology, is less dependent on the prior internal component competencies as it is on the internal absorptive capacity.

In this exploratory study we investigate the relationship of absorptive capacity and perceived knowledge distance to the decision to start actual product development and the accompanying NPD performance. In literature so far knowledge distance has not been linked to the aim of an R&D project, being product development or other. This is strange as not all R&D projects aim for new product development. Many of them are aimed for pre-product development, i.e. to do feasibility or to build a prototype as means to reduce technical and market risks. To manage this, every company nowadays uses some kind of innovation process. In most cases this is a structured process with explicit gates where it is decided prior to the project start what the aims of the R&D project are (Gann, 2005). This is done to reduce technical and business risks as well as R&D costs by reducing risks as early as possible in the innovation pipeline and to stop less attractive innovation directions in an early phase. It is hence likely that perceived knowledge distance does not only influence the R&D partner selection but also influences whether an R&D project aims to develop a product on the market, prototype a product, or conduct a feasibility study as a part of an earlier phase within the R&D cycle. When knowledge distance is perceived to be high, the R&D project will usually be set up as a feasibility or product prototype study to either build up the necessary component competencies internally or to build up a reliable supplier partnership which can bridge the knowledge distance for product development. In this case there is no intention to have a product on the market immediately. R&D managers and teams are usually able to estimate the knowledge distance quite accurately. Technical competence management is a standard practice in high tech organizations (Wagner & Hoegl, 2006; Wernerfelt, 1984). Most R&D managers manage their team's technical competence level much more explicitly than their absorptive capacity.

Many studies have linked absorptive capacity to the R&D activities of firms, as they assume that internal R&D competencies serve as an enabler of a firm's ability to recognize external trends and developments in technology and to evaluate them correctly (Veugelers, 1997; Zahra & Hayton, 2008). We join the criticizers of this idea and suggest that internal R&D capacity and external knowledge sourcing practice are in fact two complementary skills (Ebersberger & Herstad, 2011; Schmiedeberg, 2008) rather than substitutes (Chesbrough, 2006). Before the start of every new R&D project, the decision takers basically have to decide if the perceived knowledge distance they see themselves confronted with can be overcome in one development cycle or not. It can be deemed to be too high to overcome in one go. In this case product development will not be started, but development risk will be reduced by starting a feasibility or prototype project. In such a project the perceived knowledge distance is either brought down by building up internal knowledge and as such reducing the KD for the longer term and/or the knowledge distance is overcome by reassuring that external technology from a partner who bridges the knowledge distance gap can be successfully integrated. At a certain moment in time perceived knowledge distance is seen as non-problematic in terms of technical risks because either internal R&D capacity has reduced the perceived knowledge distance sufficiently and/or proven absorptive capacity is in place to work with one or more external partner(s) that fill in the remaining knowledge distance. A higher perceived knowledge distance and hence lower internal R&D capacity in a certain domain does not imply that the company is less equipped to benefit from external knowledge sourcing than a firm with low knowledge distance and high internal R&D capacity in a certain field. Having a high absorptive capacity and working with the right partners means that much less technical competence in a specific area is needed in-house to achieve outstanding NPD performance. A practical example here is FPGAs (programmable logic), where a few decades ago, almost all companies developed their own variant while nowadays, only a few large suppliers are left. All other companies merely integrate the FPGAs in their solutions, which means they are still capable of programming FPGAs and integrating them but not of developing new FPGAs themselves.

We argue that absorptive capacity is, in fact, largely independent of internal technical competencies (where knowledge distance is a reverse indication of) with respect to its association with NPD performance. A recent publication by Som, Kirner, and Jäger (2015), which found little difference between high-intensive R&D and low-intensive R&D in terms of absorptive capacity of new knowledge, supports this argument to some extent. Rosenkopf and Almeida (2003) found that when a firm creates an alliance, it is just as likely to learn from technologically dissimilar firms as from similar firms. They theorized that firms typically make the necessary investments in interfirm learning mechanisms to learn effectively from highly diverse partners. We assume a similar process when working with suppliers in that investments are made in increasing absorptive capacity when a supplier has a higher knowledge distance, making it still possible to work efficiently with such a partner without increasing the internal knowledge. In this study, we investigate similar, all high-tech R&D intensive companies in the same field, making the companies much more comparable, with the knowledge distance as well as absorptive capacity as dominant differentiators.

With this study, we contribute to the (open) innovation literature by offering:

1) An updated research model, based on practitioners' findings, which explains the selection of R&D partners and type of R&D project (product development or otherwise) based on the pre-existing organizational competencies as well as the innovation aim of the R&D project at hand.
2) The insight that absorptive capacity and technical competencies of the internal R&D team(s) are related with NPD performance in an almost independent manner. Absorptive capacity is influencing NPD performance in a positive manner, independent of the perceived knowledge distance.
3) The insight that the choice of collaboration partners depends on the knowledge distance, as perceived by the R&D team, rather than the firm's absorptive capacity.

4) Initial validation of the updated research model by means of a structural model built based on the data of 111 finished R&D projects in the semiconductor industry.

The work in this paper is based on two major assumptions: 1) that the companies use some form of a gated innovation process in R&D (Gann, 2005) and to a lesser extent 2) that R&D managers and teams know their own level of technical competencies quite well and often better than they know their own level of absorptive capacity. This study is more explorative than the previous chapters as we try to investigate what our assumption of having a gated innovation process and with that an explicit start of new product development versus different innovation aims implies for the available models in literature that describe a relation between absorptive capacity and knowledge distance on development performance.

## Literature and concepts

In this study we look into R&D projects in the semiconductor industry. Just as in other high tech industries, R&D projects in this industry nearly always involve new technology (89% of project investigated in this study). They also almost always involve at least one, but often more, external R&D partners (Chesbrough, 2006; Roberts, 2001).

### R&D partners

The literature on inter-organizational relationships separates the influence of customers (Brockhoff, 2003), suppliers, and competitors (Dussauge et al., 2000). The open innovation literature (Chesbrough, 2006) sees suppliers, customers, and universities as the most important external partners. (Laursen & Salter, 2006) include competitors, consultants, and research institutes. This study includes the following categories of partners: internal R&D, customer, supplier, university, research institute, or others that do not fit into any other category.

### Absorptive capacity

In order to absorb knowledge from external R&D partners, a company must have absorptive capacity. Absorptive capability, ACAP, is the architectural competence that influences the creation of other organizational competencies (Zahra & George, 2002) and hence in the context of external knowledge transfer absorptive capacity is a key concept. While Cohen and Levinthal (1990) originally conceptualized ACAP as the firm’s ability to identify, assimilate, and exploit knowledge gained from external sources, exploiting externally acquired knowledge usually requires converting its content into a usable form.

This is why we use the wider definition of ACAP to include transformation and hence ACAP is a collection of four distinct but complementary capabilities (Zahra & George, 2002): acquisition, assimilation, transformation, and exploitation.

*Acquisition* refers to a firm's capability to identify and acquire externally generated knowledge that is critical to its operations. Effort expended in knowledge acquisition has three attributes that can influence ACAP: intensity, speed, and direction. *Assimilation* refers to the firm's routines and processes that allow it to analyze, process, interpret, and understand the information obtained from external sources (Kim, 1997; Roussel et al., 1991). Ideas and discoveries that fall beyond a firm's search zone are overlooked because the firm cannot easily comprehend them (Rosenkopf & Nerkar, 2001). *Transformation* denotes a firm's capability to develop and refine the routines that facilitate combining existing knowledge and the newly acquired and assimilated knowledge. This is accomplished by adding or deleting knowledge or simply by interpreting the same knowledge in a different manner. *Exploitation* refers to the routines that allow firms to refine, extend, and leverage existing competencies or create new ones by incorporating acquired and transformed knowledge into its operations.

The primary input of ACAP is external knowledge inflows. This study adopts a broader perspective on external knowledge inflows to denote the aggregate amount of (tacit and explicit) complementary knowledge that the focal firm receives or gathers from other organizations following previous studies (Gupta & Govindarajan, 2000; Mom, Van Den Bosch, & Volberda, 2007). In this definition, operationalized later with questions concerning the identification, assimilation, exploitation and transformation axis, we do not include dependencies on the internal R&D as some authors do, including the amount of internal R&D done and the size of the R&D team (Cohen & Levinthal, 1990; Kobarg, Stumpf-Wollersheim, & Welpe, 2017; Xia, 2013). In order to look at the effects of knowledge distance and absorptive capacity in isolation, we use a definition and operationalization of absorptive capacity (Flatten, Engelen, Zahra, & Brettel, 2011) which is as independent from existing internal R&D capacity as possible. Still, we cannot forget that in order to be able to identify what new technologies are in a certain field, one must have some knowledge, at least a fraction, that relates to this new knowledge (Cooper, 1994), so absorptive capacity can never be seen as a competency in splendid isolation from component competencies but we do believe that can be seen as almost isolated as only a small fraction of knowledge has to be assumed. (Flatten et al., 2011)

**Knowledge distance**

Knowledge distance is usually defined as a function of the extent to which two knowledge entities are technologically related (Makri et al., 2010; Rosenkopf & Nerkar, 2001), but within a knowledge sourcing context, we define knowledge distance (KD) as the focal firm's knowledge base relatedness to the new technology that it seeks to obtain (Peeters, 2013). This will also influence the ease with which new knowledge and prior knowledge are integrated. At least a fraction of new knowledge needs to be related to prior knowledge (Cooper, 1994). Before searching for partners, the focal firm will assess the knowledge distance between its internal competencies and the new technology needed in the project. KD is closely linked to search, as it is one of the dimensions along which search can be targeted (Rosenkopf & Nerkar, 2001). The KD between the focal firm's technical competencies and the new technology has been found to influence the likelihood of finding search results and the value of those results (Levinthal & March, 1993; March, 1991). We assume that the product management team with the internal R&D team assesses the KD between the own internal R&D unit and the new technology needed. When the perceived knowledge distance is high, it is more likely that the internal R&D unit will look for R&D partners that can bridge the gap. It is also more likely in this case that steps will be taken to reduce the (technical) risks before going into product development by means of a feasibility study or prototype building. When the knowledge distance is low, it is more likely that the internal R&D unit can easily bridge the gap themselves. It is also more likely that the aim of the R&D project is then focused on product development as technical risks are deemed to be low. Therefore, we assumed that there is a relationship between KD and the choice of partners as well as the aim of a project to deliver a product to market (PtM) and introduced KD as an independent variable in our model.

**The gated innovation process: pre-product R&D projects versus product development**

So far, we have not taken into account that companies manage their innovation process to make best use of their limited resources in times of budget, people and management attention. Nowadays most companies do active portfolio management of their R&D and have come up with a formalized NPD process. An important concept and an important assumption underlying our hypothesis development is the idea that most companies use a gated or pipelined innovation process (Chesbrough, 2006). R&D projects in a complex environment nearly always use new technology, which is often sourced externally. Hence, it is important to understand the new technology maturity and to reduce development risks by using a gated R&D portfolio management process. Different companies define this innovation process differently; however, well accepted and most commonly used in the high tech industry is a variant of a gated process introduced by NASA and later simplified by Cooper (Gann, 2005). This gated innovation process uses Technology Readiness levels as an indication for the stage where the R&D process is in, especially with (partial) external technical sourcing of the different critical technology elements that make up a new system. Technology Readiness Levels were originally conceived at NASA in 1974 and formally defined in 1989 making it possible to consistently validate the technical maturity across a wide range of different technologies. The original definition included seven levels, but in the 1990s NASA adopted the current nine-level scale that subsequently gained widespread acceptance, though it has limitations for certain technologies, most notably for purely software based systems. An overview of the TRL's and its implication can be seen in Figure 11. A comprehensive approach and discussion about TRLs has been published by the European Association of Research and Technology

Organizations (EARTO, 2014).

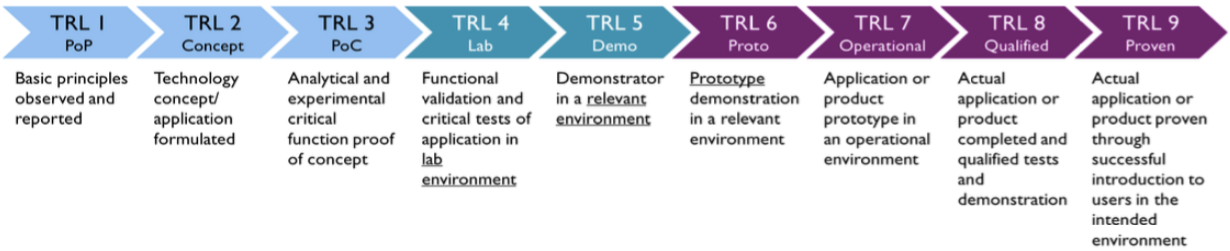


*Figure 11 Technology readiness levels overview*

Most high tech companies have come up with a formalized NPD process which looks like a funnel being wide to the left (far away from product development) and small to the right (actual product development). There usually are many small scale R&D projects (internal or with external partners) for TRL1-3, a medium number of medium scale R&D projects for TRL4-5, and then a true product development cycle for TRL6-9 with a limited number of large scale R&D projects. Between each of these R&D projects, as well as within these projects according to TRL levels achieved, explicit Go/No Go milestones will be defined based on technical performance but also financial indicators and market responses. Coupling knowledge distance with TRL levels, in many cases TRL level will be lower when the knowledge distance is high. In that case companies will introduce pre-product R&D projects that do not aim to get a product to the market but that aim to either build up the internal component competencies that reduce the knowledge distance or build a proven relationship with an external partner that bridges the knowledge gap in that way.

In this study, we explicitly make a distinction between all R&D projects done before the actual start of product development, i.e. all projects aiming for TRL 1-5. These pre-product R&D projects (including feasibility, demonstrator and prototype development), contrary to actual new product development R&D projects, i.e. a NPD project aiming for TRL 6-9. We believe that most, if not all, high tech companies in this domain know before the start of a R&D project if the intent is to have a product to the market (i.e. actual product development) or if the R&D project is enabling (pre-product development): hence to de-risk development, build up new competencies, do a feasibility study and so on.

### New product development performance

The new product development performance of a single R&D product development project (aiming for TRL 6-9) can be judged by three main performance metrics: speed of development (leading to time to market advantage), quality of the product (the outcome of the project) and cost of development. While the cost of the development is an important parameter as well, it could not be measured in this study for confidentiality reasons or inability of the respondents to provide this information.

## Hypotheses

Several studies have assumed that knowledge distance and absorptive capacity are fully complementary and that reduction in knowledge distance is necessary for successful product development. For example, Liyanage and Barnard (Coombs, 1996) found that transition from one technology paradigm to another is possible only when the knowledge distance is minimal and the transition process has a correspondingly high value of absorptive capacities. This would mean that knowledge distance and absorptive capacity are fully complementary. However, we think that their findings correspond to a specific situation in which no partners are chosen that deliver core knowledge from outside the firm’s boundary in the long-run, as in the case of, e.g., critical suppliers. Their study is based on cases in life science technology, where knowledge is frequently gained by acquiring a startup firm rather than long-term vertical specialization and collaboration between firms with specific knowledge, as is the case in most technology, software, and automotive product development. When not working with external partners in product development, knowledge distance needs to be reduced to the extent that the internal R&D of the firm is capable of picking it up itself. However, in the case of long-term vertical specialization, the internal R&D of the firm needs to be capable of building a close supplier relation, and it needs to have enough understanding of the supplier's knowledge to be able to write sufficiently detailed system specifications and to be able to judge the quality of the final component that the supplier delivers. It is however not necessary to build the same knowledge as this (critical) supplier has. We, therefore, argue that *the selection of R&D partners itself is, in fact, merely dependent on the KD* and not only on absorptive capacity (ACAP) as the latter has been shown in many studies (Ku et al., 2016; Rebolledo, Halley, & Nagati; Ryzhkova & Pesamaa, 2015).

The choice of partners depends on the KD for the following reasons. External R&D partners can be divided into Suppliers, Customers, Universities & Research Institutes. The importance of customers, as a part of the R&D process, has long been recognized to help define the needed innovations and, therefore, reduce the risk associated with their market introduction (Kline & Rosenberg, 1986; Roy Rothwell, 1977; R. Rothwell & Gardiner, 1985; Von Hippel, 1978). Most of their contributions come from understanding system requirements and user behavior and from promoting innovation acceptance and adaptation by other firms within the same user community (Shaw, 1994). They sometimes also provide complementary technical expertise. When knowledge distance is low, projects will often lead to a product on the market or will deliver new versions of existing projects. customer contributions in terms of system requirements and user behavior are then of particular importance; hence, we expect frequent involvement of customers. When knowledge distance is medium to high, the arguments for pushing innovation acceptance and adaptation by other firms as well as specific technical know-how become more important. We still expect customers to be somewhat involved in the projects but less so than in case of low knowledge distance.

Suppliers are used mainly for efficient implementation, i.e., cost reduction purposes. or capacity reasons (Cohen & Levinthal, 1989, 1990). In these cases, knowledge distance is expected to be low. In special cases, there can be a critical supplier that delivers a subsystem, which the company cannot develop independently. In such a case, the knowledge distance to the inside of the subsystem can be high, but the subsystem has to be integrated without problems, so the knowledge distance cannot be high at the outside of the subsystem. When knowledge distance to the outside of the subsystem is high, the expectation is that in such a case, a feasibility or prototype development will be done to reduce knowledge distance to the interfaces of the subsystem between the two companies before actual product development.

In another way, one could describe this as investing in absorptive capacity to such an extent that the receiving company can integrate the supplier's technology without problems.

While the literature does not differentiate between universities and research institutes, in reality, they tend to fulfill different roles. Universities conceptualize new ideas, which in a technical environment usually means they come up with a new theory and an initial rough validation of its possible implementation. Research institutes bridge between universities and industry by transforming research results into easier to integrate in product results, i.e., they offer a more complete, easier to transfer proof of concept. Both focus on new innovations, concepts, and knowledge that are not widely used yet in the products on the market. As such, they are knowledge brokers when knowledge distance is medium to high. In many cases, they contribute to feasibility studies and prototype development rather than product development within a company.

Combining these observations, the expectation is that in the selection of collaboration partners, lower knowledge distance tends to favor suppliers and customers while higher knowledge distance tends to favor research institutes and universities in an effort to build-up component competencies in-house or a strategic supplier when a company has no intention to build-up the technical competencies in-house. So we know from literature that *the choice of R&D partners depends on the perceived knowledge distance* and we will validate this known result once more in our study.

Using a gated innovation process, practitioners at large have a good idea of the knowledge and technology gaps in their new developments: they know quite well what their own R&D team can and cannot do. In vertically integrated industries, they build long-term relationships with R&D partners and hence, they also know well what their R&D partner can and cannot do. The focal firm hence decides about the intended outcome of the R&D project being feasibility, prototyping, or actual product development based on the perceived knowledge distance, technical uncertainties, and their (prior) working relationship with the external partner(s).

Coupling knowledge distance with TRL levels, in many cases, the TRL level will be lower when the knowledge distance is high. When knowledge distance is lower, chances that an R&D project will lead to product market introduction (PtM) are higher. Hence, as soon as companies realize that the knowledge distance with the new technology compared to their current component competence is high, they will often introduce projects that do not aim to get a product to the market directly but that aim to reduce the risk of such a product development by doing a feasibility study or building a prototype, which explicitly aims to build familiarity with the new technology to achieve two distinctively different objectives:

1) to build the technical competencies of the focal firm's internal R&D team(s) in case of working with universities or research institutes, which increases the focal firm's component competencies in this field and reduces the knowledge distance of the focal firm, or
2) to build up enough knowledge and knowhow to do the integration of technologies well in case of (critical) suppliers. This improves the focal firm's integrative capacity for this new technology as part of its absorptive capacity.

Both approaches aim to reduce risk before actual product development. When knowledge distance is lower, the technical risks of a project are lower. The reasons for this are twofold: the aim of the project is more often the development (rather than prototyping or feasibility study), and the development risks of integrating new technologies are lower when knowledge distance is lower.

*Hypothesis 1: Compared to projects with a higher perceived knowledge distance, projects with a lower knowledge distance have a higher chance that the outcome of the R&D project is to bring a product on the market.*

R&D managers and teams are usually capable of estimating the knowledge distance quite accurately. Technical competence management is standard practice in high tech organizations (Wagner & Hoegl, 2006; Wernerfelt, 1984). On the contrary much less attention is given to the absorptive capacity which an R&D team possesses. The decision if a product has to come to market is taken on the bases of market and customer input as well as technical risks which are foreseen, but most companies do not assess their own absorptive capacity as part of the decision process to go to market. Hence limitations in absorptive capacity is rarely if ever seen as a deal breaker. Therefore we hypothesize that the outcome if an R&D project leads to a product on the market is actually rather independent of the absorptive capacity.

*Hypothesis 2: A lower perceived knowledge distance is more strongly associated with whether or not the outcome of an R&D project is a product on the market than the level of absorptive capacity is.*

If an R&D project brings a product to the market, the product quality and development speed are highly dependent on the ACAP, as we know from the literature that a higher ACAP improves NPD performance (Witzeman et al., 2006; Xia, 2013). In this study, we validate that a higher ACAP is indeed associated with better NPD performance, both in terms of speed as well as quality. In this way, absorptive capacity is almost independent to technical competencies, especially when there are limited internal R&D activities in the field of the new technology at hand.

*Hypothesis 3: A higher absorptive capacity is associated with better NPD performance for projects with a product to market outcome*

From the literature, we expected that higher ACAP influences the NPD performance in projects were new technology is introduced and/or developed in a positive way, assuming long-term partnerships during the product development cycle. The usual assumption is that NPD performance, as defined by the product quality and time to market, is *also* dependent on knowledge distance. A higher knowledge distance leads to a lower NPD performance.

However, companies use a stage-gate innovation process to reduce risk and build either 1) enough internal technical competencies or 2) enough absorptive capacity to integrate external knowledge from a trusted partner to bring a product to the market in the end. Hence, if that is the case, knowledge distance should not be significantly associated with the NPD performance of the final product development project. Does the use of the stage-gate process help overcome the dependency of knowledge distance on NPD performance? Once we get to the stage of actual product development, one out of two situations may occur:

1) the knowledge distance will be low enough not to relate with NPD performance, based on the literature assuming that focal firm themselves is the most important partner (see Chapter 2). We reduce the knowledge distance, i.e., build our internal competencies until the knowledge distance is low enough to get a product to the market; or
2) the risk reduction steps necessary to work with a (critical) R&D partner (see also the idea of a most important partner other than the focal firm itself in Chapter 2) have been made and absorptive capacity, specifically the integrative capacity for this particular type of knowledge, is supposedly high enough to overcome a remaining high knowledge distance in product development. In this case, the focal firm profoundly uses the knowledge of its R&D partner to the extent that they do

not need to build the competencies internally. Needless to say, the level of trust in the R&D partner is high. This mechanism could explain why it is possible, with the right incentives and organizations in place, to truly outsource a critical part of product development over a long time without a large internal R&D team on the subject.

Based on this, we move away from the traditional assumption that KD influences development performance in all cases, e.g. even in projects with a product to market outcome. When the gated innovation process works effectively, a project is aimed at a product to market only when the remaining knowledge distance does not matter anymore as it is either low or truly outsourced to a critical supplier or customer and the integration in the product has been proven prior.

*Hypothesis 4: Absorptive capacity is more strongly associated with the NPD performance of projects with a product to market outcome than knowledge distance is.*

A higher absorptive capacity is associated with better NPD performance. However, relying on the staged innovation practice common in the industry, we believe that knowledge distance determines whether a product comes to market (PtM): the higher the knowledge distance, the less chance that the R&D project leads to a PtM. Nevertheless, sometimes a product can come to the market even when the knowledge distance remains high. In this case, a collaboration partner that can fill up this hole has been found. The most important partner, in this case, might not be internal R&D but a critical supplier or lead customer, as we have shown in Chapter 2 of this thesis. The integrative capacity of the internal R&D team has to be such that they can integrate the results of the external partner, but the aim is not necessarily to further reduce knowledge distance when there is a trusted long term R&D partner. This trusted R&D partner can take over the need for a large internal technical competence in certain areas. While knowledge distance is related with the choice of collaboration partners and the chances that a project leads to a product on the market, ACAP is mainly related with NPD performance and not KD. The hypotheses are summarized in Table 16.

*Table 16*
*Hypothesis Summary*

| Nr. | Hypotheses |
|---|---|
| H1 | Compared to projects with a higher perceived knowledge distance, projects with a lower knowledge distance have a higher chance that the outcome of the R&D project is to bring a product on the market. |
| H2 | A lower perceived knowledge distance is more strongly associated with whether or not the outcome of an R&D project is a product on the market than the level of absorptive capacity is. |
| H3 | A higher absorptive capacity is associated with better NPD performance for projects with a product to market outcome |
| H4 | Absorptive capacity is more strongly associated with on the NPD performance of projects with a product to market outcome than knowledge distance is. |

In summary, we expect significant effects, as shown in our research model in Figure 12.

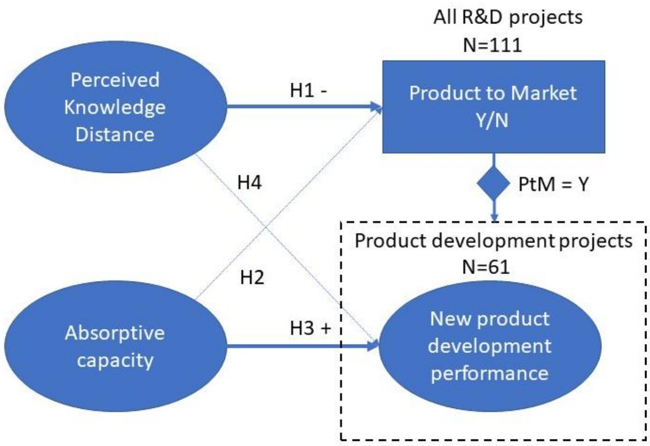


*Figure 12. Research model showing the expected effects of KD and ACAP on PtM and NPD performance.*

## Data and method

### Data collection and characteristics

This study tests the associations between knowledge distance, absorptive capacity, partner choice (research institute, customer, suppliers, universities, and other), and the PtM outcome and NPD performance.

An online questionnaire was developed and e-mailed to 7841 addresses available in the International Technology Forum (ITF) database. Imec, one of the top three worldwide research organizations in semiconductor technology, organizes ITF as a yearly event series in Europe, Japan, Korea, Taiwan, and the US. These events are open to non-partners as well as Imec partners in the semiconductor industry, and they are usually well visited by representatives of almost all significant semiconductor companies.

The data used for testing the multinomial logit model were gathered from persons working in the semiconductor industry. The invitation to participate e-mail was constructed according to the guidelines in (Dillman et al., 2008). Responses were requested from semiconductor industry professionals that are senior and hold positions involving decision power. We collected data from June 19 until July 23 in 2013 and observed 235 responses, of which 111 are complete. About 50% of respondents discontinued after answering a few questions. The fact that most of the other respondents stopped answering the questionnaire quite quickly, together with a high level of experience of the people who did complete the questionnaire, gives us confidence that the right people have answered the questionnaire and that people who lacked expertise decided that the questionnaire was not for them and dropped out. Eighty percent of these respondents have worked in the semiconductor industry for more than ten years and thus have seen a considerable number of projects as a frame of reference. The size of projects they have worked on varied from very small (just one person) to very large (>1000 people and a $100M budget/year). The geographical response distribution of respondents was spread reasonably worldwide, with responses from all significant semiconductor areas of the world, i.e., Japan, Taiwan, Korea, America (includes Canada), and (Northern) Europe. Our belief in the accuracy of the results is supported by several studies that have shown that surveys with lower response rates often have more accurate measurements than surveys with higher response rates (Keeter et al., 2006; Visser et al., 1996).

One of the biggest potential issues with surveys is common method bias (CMB), i.e., the variations in responses are caused by the instrument rather than by the actual predispositions of the respondents. By using validated questions from earlier studies as well as doing multiple test-rounds of the questionnaire to refine the new questions, we intend to limit the CMB. We guaranteed the anonymity of the respondents to avoid socially acceptable (positive) answers. We asked for a finalized project to avoid the positive outcome bias when still actively working on an activity. In the results section, we report CFA and variable characteristics to further validate that CMB is not a real issue in this dataset.

For this study, we considered only projects in which new technology (new to the company, new to the industry, or new to the world) played a role. This led to a final sample size of 111. We checked for non-response bias by comparing the characteristics of the respondents' companies to those of the targeted population sample. The respondents represented 7 out of the top-10 semiconductor companies. One hundred and thirteen different companies were involved, from small startups to large industries. No company was overrepresented in the response: one company had 6 respondents, one had 5, three companies have 3 respondents, and all other companies had 1 or 2 respondents. No differences were found between early and late respondents (Armstrong, 1977) in general characteristics, such as role or experience in the industry (p=0.76) or geographical location (p=0.70), which suggests no non-response bias.

The questionnaire was adapted from an earlier instrument (Peeters, 2013) on absorptive capacity and knowledge use in the gaming industry. Questions were removed when not relevant for the current study and additional pre-tested questions were added (Praest Knudsen & Bøtker Mortensen, 2011; Steensma & Corley, 2001). The final instrument is included in Appendix 1.

We highlight some important characteristics of our survey group to make the later results easier to interpret. Our data showed that in 89% of all projects, technology new to the company was used, suggesting that using new technology in product development is a daily practice in semiconductor companies. The degree of newness of technology was distributed normally over 'new to the world (30%), new to the market (30%), and new to our company (40%).'

Figure 13 shows who participated in the product development process.

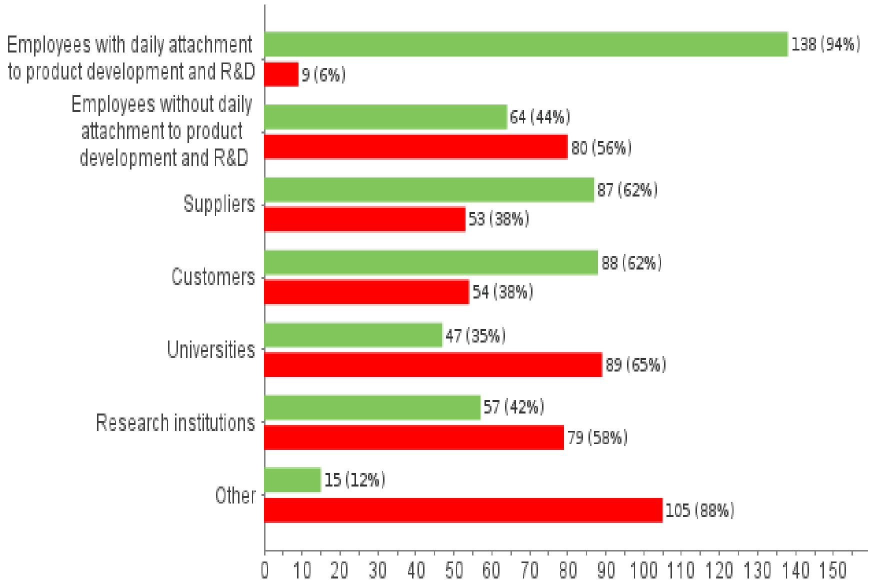


*Figure 13. Who participated in the new product development project? (green= involved, red = not involved).*

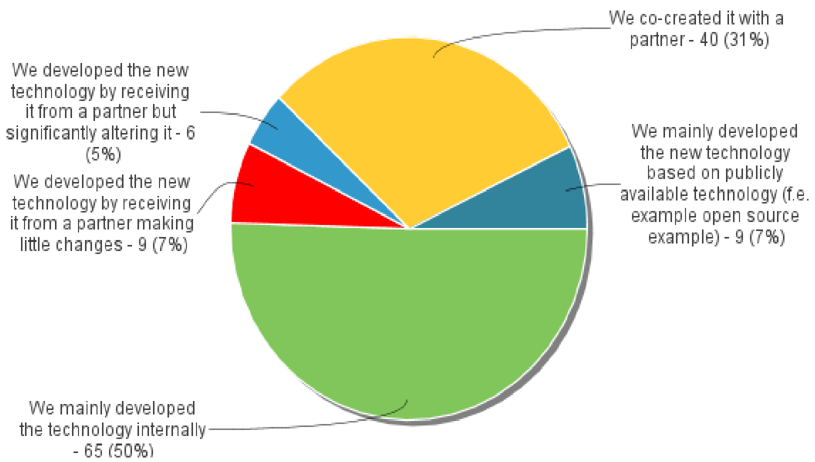


*Figure 14. Which statement applies best to your most recently finalized project?*

Figure 13 also shows that product development in the semiconductor industry almost always involves partnering with external R&D partners and in many cases with more than one external party. Customers were participating in almost two thirds of all projects, and the same was true for suppliers. In nearly half of the projects, one or more research institutes were involved. In half of all product development initiatives, external knowledge dominated the product creation process.

**Operationalization of variables**

Most items were assessed on Likert response scales ranging from 1 “strongly disagree” to 7 “strongly agree”. A “not applicable” was added as well as the possibility to skip questions.

**Outcome variables**

Measured dependent variable, *Partner involved.*, was measured with an item, ”Who has actively participated in the new product development (NPD) process?,” on a 7-point scale, including Employees with daily attachment to R&D, employees without daily attachment to R&D, Suppliers, Customers, Universities, Research Institutes, and other. Of course, multiple R&D teams can be involved in one single R&D project. As can be seen in the results, most R&D projects actually have multiple partners.

Measured variable *Product to Market (PtM)* was assessed using a simple statement, “The project leads to a product that became available to the market,” on a binary Y/N scale coded as Y=1 and N=0. From the 111 projects investigated, 61, or about 55%, led to a product on the market.

Latent variable *new product development Performance (NPD performance)* of a single R&D project that intends to bring a product to market can be judged by three performance metrics: speed of development (leading to time to market advantage), quality of the product, and cost of the development. The scale developed by Knudsen and Mortensen (Praest Knudsen & Bøtker Mortensen, 2011) was used, but the original semantic scale was changed to a Likert scale and “don’t know” option was added. Only two NPD performance metrics were employed in this study, speed and quality, as we were unable to get reliable input on the cost of development compared to others in the market. Many of the respondents indicated they could not judge the cost. Speed to market (Griffin, 1993) refers to the length of time it takes from the beginning of the NPD project until the product launch. We compared this within the industry, expectation, and typical product development within the company (7-point Likert scale). The quality of the product was operationalized by asking respondents to compare their products with alternatives in the market (7-point Likert scale). This question applies only to NPD projects that actually delivered a product to the market. In our case, we had 111 finalized projects of which 61 projects delivered a product to the market. Quality of the product can be assessed only for projects that deliver a product to the market. Cronbach’s alpha of the final item-scale was 0.82 for questions C1-C5.

**Independent variables**

As described above, we operationalized the variables that relate the choice of the partner collaboration, product to the market, and product development quality and speed with external knowledge distance, absorptive capacity, external knowledge usage (control), and innovation strategy (control).

To measure the latent variable *perceived knowledge distance,* four questions were asked measured on a 7-point (inverted) Likert scale ranging from 1 “Strongly disagree” to 7 “Strongly agree.”. It is important to realize that while these questions come from literature (Steensma & Corley, 2001)and have been validated in a few environments (Peeters, 2013; Steensma & Corley, 2001), they have not been used nor validated in the semiconductor environment and hence not only measurement error but also precision of these questions in reflecting the perceived knowledge distance is less than optimal. Cronbach’s alpha for these four questions was .66. The use of a SEM framework in this Chapter instead of more traditional linear regression methods is helping to overcome the potential problems of measurement error and lack of precision.

Latent variable, absorptive capacity, developed by Lichtenthaler (Lichtenthaler, 2009) comprised 10 questions.[4] Also the precision and scale of absorptive capacity is still under development, for example Flatten has suggested a new line of questioning and scale to measure absorptive capacity (Flatten et al., 2011), that is also not widely accepted within the academic environment yet. Absorptive capacity by any line of questioning has to the best of the authors’ knowledge not been tested in a semiconductor environment before and also here we have to assume that the precision of using these questions to measure absorptive capacity is still less than optimal. The use of a SEM framework in this Chapter instead of more traditional linear regression methods is helping to overcome the potential suffering of measurement error and precision.

**Control variables**

Creating new knowledge involves combining internal and external knowledge in a novel fashion (Bapuji & Crossan, 2004; Bierly & Chakrabarti, 1996; Vera & Crossan, 2004) . When looking at the integration aspect, one can distinguish three main categories of

[4] After development and implementation of our questionnaire, Lichtenhaler’s paper has been retracted because it reported fraudulent regression results. As far as the authors are aware, this fraud did not include scale manipulation; hence, we assume that we can still use the questions and scale for absorptive capacity developed by him.

integrating external knowledge with internal knowledge. This *external knowledge usage* (*EKU*) can be defined as internal, replication, or recombination.

Measured variable *external knowledge usage* was measured using the question, “Which statement applies best to your most recently finalized project?” The statement “mainly developed internally” reflects the knowledge use, the statement “ received from a partner but made little alterations” reflects replication, and the statement “we co-created it with a partner” reflects a recombination strategy. The answer “we mainly developed the new technology on publicly based available technology” was ignored, as it does not indicate whether the knowledge use strategy is mainly internal, replication, or recombination. This is a topic to consider in future research. Additionally, the answer “we received the new technology from a partner but significantly altered it” was ignored in the analysis, as it did not discriminate sufficiently between an complementary knowledge use strategy and a recombination strategy. Many studies have emphasized that firms must be able to absorb and use the knowledge effectively if they are to benefit from external knowledge (Bönte, 2005; Griffith & Harvey, 2004). (Roussel et al., 1991) showed that the knowledge-use strategy influences the sourcing strategy and allows or excludes certain use of knowledge; thus, we controlled for EKU in our research model.

Measured variable *R&D prime objective* was measured by asking respondents to select the single most important decision criterion out of the following list:

1. Build-up internal competence for the future
2. Lowest overall cost
3. Highest product performance
4. Shortest time to market
5. No internal resources available
6. And Other (open).

The open answer category “others” contained 5% of the answers, 95% fall into the categories as found in the literature.

More than 95% of all answers fell into the first 5 categories found in the literature; hence, the selection of criteria was reliable. Before asking what the most important decision criterion was, we also asked which decision criteria played a role in the decision process. In most projects, there was a trade-off between multiple decision criteria, although respondents were always able to identify the most important decision criterion, an indication that while decision processes include trade-offs, there usually is a clear understanding of what is most important to achieve in this project.

## Data analysis

We tested hypotheses 1 to 4 using a structural equation model with a WLSMV estimator and delta parametrization. Prior to that, we used confirmatory factor analysis (CFA) to check the validity and unidimensionality of the constructs in the measurement model, even though these were all validated in prior literature, some of them specifically knowledge distance and absorptive capacity, have not been tested in a similar environment before. The constructs in the measurement model are valid.

Table 18 shows the descriptive statistics and correlation matrix. All analyses were done using MPLUS (Muthen, 2015). We report standardized coefficients for easier comparison between models.

To analyze Hypotheses 2 and 4, two structural equation models (SEM) were compared in line with the method proposed by (Anderson & W., 1988) as we use SEM in this paper to develop our exploratory theories on the relative independence between knowledge distance and absorptive capacity when R&D partners are involved. We try to make a meaningful inference over the situation that over time, trust is built up with an external R&D partner and they can then replace for a large part the need to have component competency in the internal R&D team, assuming that the absorptive capacity of the focal firm is high enough. The first structural model, shown in Figure 15, assumes a relationship between ACAP and PtM as well as KD and NDP performance in addition to relationships between KD and PtM and between ACAP and NPD performance.

The model in Figure 15 had an acceptable fit to the data RSMEA = 0.032; CFI = 0.934, TLI = 0.921. The standardized coefficient between KD and PtM is -0.32 with $p<0.01$, hence H1 is supported. The standardized coefficient between ACAP and NPD is 0.50 with $p<0.001$ and as such H3 is supported. The standardized coefficient between ACAP and PtM was -0.05, which is 7 times smaller and reversed signed than the coefficient between KD and PtM, which was -0.32 but non-significant. The standardized coefficient between KD and NDP performance is -0.16, which is 5 times smaller than the standardized coefficient between ACAP and NPD, being 0.5 but the coefficient is again non-significant. Thus, the first model does not invalidate H2 and H4 in the sense that the coefficients found are much smaller and non-significant. However the 95% confidence intervals (CI), shown in Table 17, of the two paths overlap in both cases. We see that the highest absolute value of the path coefficients within the CI is such that it is possible that the standardized coefficient between KD and NPD becomes larger than the standardized coefficient between ACAP and NPD. Similarly, the standardized coefficient between KD and PtM can become smaller than the standardized coefficient between ACAP and PtM. Hence looking at this model we cannot validate hypothesis 2 and 4. The coefficients between ACAP and PtM is non-significant and near-zero; therefore, we wondered whether the relationship is really there. The effect of ACAP on NPD performance remained five times larger compared to the effect of KD on NPD performance and the effect of ACAP on PtM remained nearly zero. This leads us to believe that a model without assuming these effects could provide a better fit.

When we updated the SEM model to assume no interaction of ACAP with PtM and KD with NPD performance, as shown in Figure 16, the coefficients between KD and PtM and between ACAP and NPD performance did not significantly change in value or size and are statistically significant but the structural model fit improved significantly: RSMEA = 0.026, CFI = 0.955, TLI = 0.946. We retained the second structural model because of a better fit. Table 19 presents the results of the second, better fitting, structural model.

*Table 17*
*Confidence Intervals structural model 1*

| | Confidence Intervals | | |
|---|---|---|---|
| | Lower 2.5% | Estimate | Upper 2.5% |
| ACAP ->NPD | 0.27 | 0.50 | 0.73 |
| KD -> NPD | -0.48 | -0.16 | 0.17 |
| ACAP -> PtM | -0.31 | -0.05 | 0.21 |
| KD -> PtM | -0.57 | -0.32 | -0.07 |

*Table 18*
*Descriptive Statistics. Variance on the Diagonal.*

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | PM | .50 | | | | | | | | | | | | | | | | | | | | | |
| 2 | C1 | .02 | .86 | | | | | | | | | | | | | | | | | | | | |
| 3 | C2 | .00 | .37 | 2.54 | | | | | | | | | | | | | | | | | | | |
| 4 | C3 | .00 | .13 | .30 | 3.34 | | | | | | | | | | | | | | | | | | |
| 5 | C4 | .00 | -.34 | -.51 | -.54 | 3.09 | | | | | | | | | | | | | | | | | |
| 6 | C5 | .00 | .24 | .48 | .47 | -.37 | 1.90 | | | | | | | | | | | | | | | | |
| 7 | KD0 | -.13 | .22 | .07 | .12 | -.09 | .03 | 2.37 | | | | | | | | | | | | | | | |
| 8 | KD1 | -.29 | .04 | .13 | .14 | -.00 | .19 | .38 | 3.02 | | | | | | | | | | | | | | |
| 9 | KD2 | -.25 | .09 | .04 | -.18 | 0.15 | -.31 | .33 | .30 | 3.10 | | | | | | | | | | | | | |
| 10 | KD3 | -.16 | 0.11 | -.06 | -.24 | .25 | -.37 | 0.26 | .17 | .75 | 3.10 | | | | | | | | | | | | |
| 11 | I0 | -.04 | .10 | .14 | .26 | -.20 | .22 | .00 | .01 | .06 | -.03 | 1.08 | | | | | | | | | | | |
| 12 | I1 | .04 | .16 | .14 | .22 | -.27 | .20 | .09 | .04 | .01 | -.14 | .67 | .90 | | | | | | | | | | |
| 13 | I2 | -.09 | -.01 | .13 | .31 | -.29 | .17 | .08 | .08 | .12 | .05 | .68 | .62 | 1.44 | | | | | | | | | |
| 14 | I3 | -.12 | .26 | .22 | .10 | -.24 | .28 | -.01 | .07 | .07 | -.05 | .45 | .43 | .54 | 1.28 | | | | | | | | |
| 15 | I4 | .11 | .06 | .17 | .34 | -.19 | .28 | -.10 | -.11 | .00 | -.00 | .36 | .34 | .32 | .35 | 1.63 | | | | | | | |
| 16 | I5 | .04 | -.07 | .20 | .30 | -.17 | .16 | -.14 | -.09 | .03 | .11 | .32 | .2 | .33 | .19 | .57 | 1.71 | | | | | | |
| 17 | I6 | -.00 | -.12 | 0.07 | .30 | .09 | -.01 | -.05 | 0.06 | .12 | .06 | -.08 | -.18 | -.07 | -.24 | -.18 | -.09 | 2.33 | | | | | |
| 18 | I7 | -.12 | .23 | .15 | .12 | -.14 | -.01 | -.05 | .06 | .12 | .08 | .37 | .41 | .45 | .52 | .31 | .27 | -.31 | 1.03 | | | | |
| 19 | I8 | .01 | .44 | .42 | .30 | -.49 | .20 | .04 | -.01 | .06 | -.07 | .27 | .31 | .38 | .55 | .19 | .05 | -.26 | .48 | 1.36 | | | |
| 20 | I9 | .02 | .20 | .16 | .11 | -.26 | =.01 | -.07 | -.07 | .10 | .07 | .37 | .30 | .39 | .42 | .21 | .15 | -.15 | .46 | .44 | 2.26 | | |
| 21 | PO | -.04 | .04 | .12 | .02 | .03 | .19 | -.06 | .14 | -.06 | -.02 | -.03 | .01 | .02 | .06 | -.06 | .05 | -.04 | .12 | -.12 | -.22 | .54 | |
| 22 | EKU | -.04 | .06 | .03 | .12 | .09 | .17 | .10 | .22 | .09 | .16 | .08 | -.04 | .20 | .05 | .01 | -.04 | .08 | .06 | .07 | .06 | -.04 | .23 |
| | MEAN | .55 | 6.23 | 5.03 | 4.49 | 3.78 | 4.78 | 5.29 | 4.41 | 4.53 | 4.07 | 5.76 | 5.89 | 5.44 | 5.27 | 4.90 | 4.47 | 3.53 | 5.37 | 5.24 | 4.96 | 2.04 | .36 |

*Table 19*
*Measurement Model*

| **Variables** | **Standardized Loading** | **SE** |
|---|---|---|
| *Knowledge distance* | | |
| KD0 Highly trained personnel needs to be hired to develop this technology in-house | .50 | .09 |
| KD1High investment in equipment or staff needed to develop this technology | .49 | .08 |
| KD2 The cost to develop this technology in-house independently would be greater than our previous development efforts | .74 | .08 |
| KD3 The total cost to develop this technology within our firm would have been significantly greater as compared to the average cost of other technologies that our firm has independently developed in the past | .57 | 0.09 |
| | | |
| *Absorptive capacity* | | |
| I0 We frequently scan the environment for new technologies | .70 | .05 |
| I1 We thoroughly observe technological trends | .69 | .05 |
| I2 We observe in detail external sources of new technologies | .77 | .05 |
| I3 We regularly match new technologies with ideas for new products | .71 | .05 |
| I4 We quickly apply internally developed technology in new products | .49 | .08 |
| I5 We easily implement acquired technology in new products | .36 | .09 |
| I6 It is well known who can best exploit newly developed technologies within our firm | 0.22 | 0.08 |
| I7 We thoroughly maintain relevant technology and/or knowledge over time | .64 | .05 |
| I8 We communicate relevant technology developments across units of our firm | .57 | .07 |
| I9 We are proficient in reactivating existing knowledge for new uses | .54 | .07 |
| | | |
| *New product development performance* | | |
| C1 The quality of the product is clearly better than other alternatives on the market | .49 | .13 |
| C2 The product was introduced on the market at the planned timing | .61 | .13 |
| C3This product development has overall been faster than the norm in the industry | .63 | .13 |
| C4 This product development has overall been faster than our expectation | .76 | .14 |
| C5 This product development has overall been faster than a typical product development project in our firm | .55 | .10 |
| | | |
| *Model fit of structural model 2* | | |
| RSMEA | 0.031 | |
| CFI | 0.924 | |
| TLI | 0.912 | |

*A factor loading of 1.000 means that the observed variable is used to fit the scale of the latent variable.*

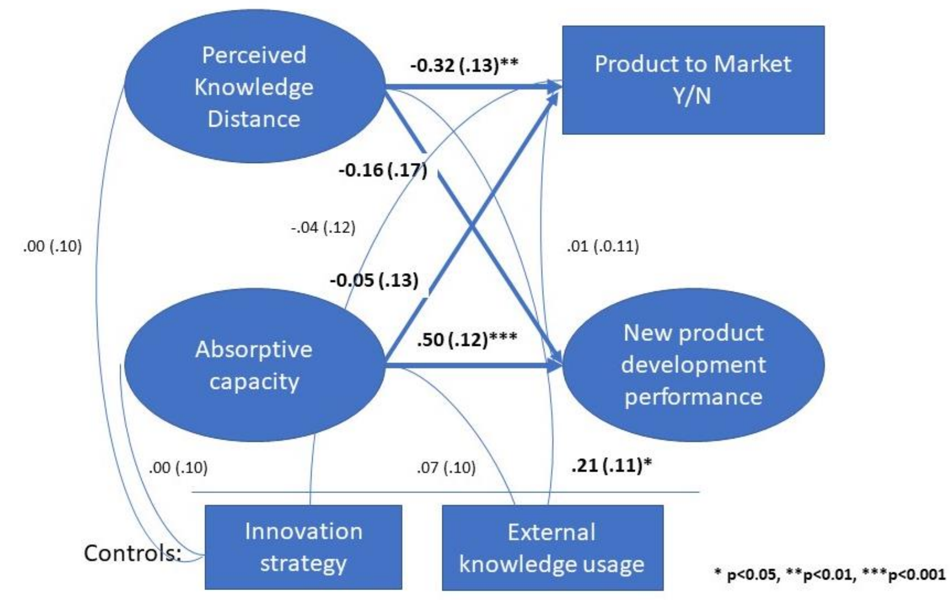


*Figure 15. Structural model 1 with standardized coefficients and standardized error between brackets assuming significant effects of ACAP on PtM and of KD on NPD performance.*

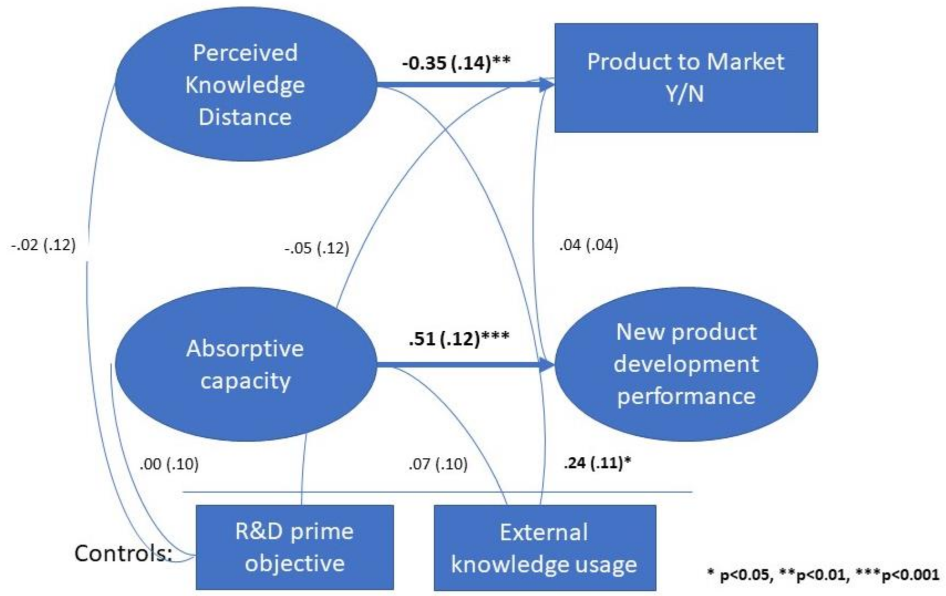


*Figure 16. Structural model 2 with standardized coefficients and standardized error between brackets assuming no effect of ACAP on PtM or effect of KD on NPD performance.*

## Results

As expected from literature with respect to partner choice, research institutes and universities are more involved when external knowledge distance is higher while suppliers are more involved when knowledge distance is low to medium as visually shown in Figure 17.

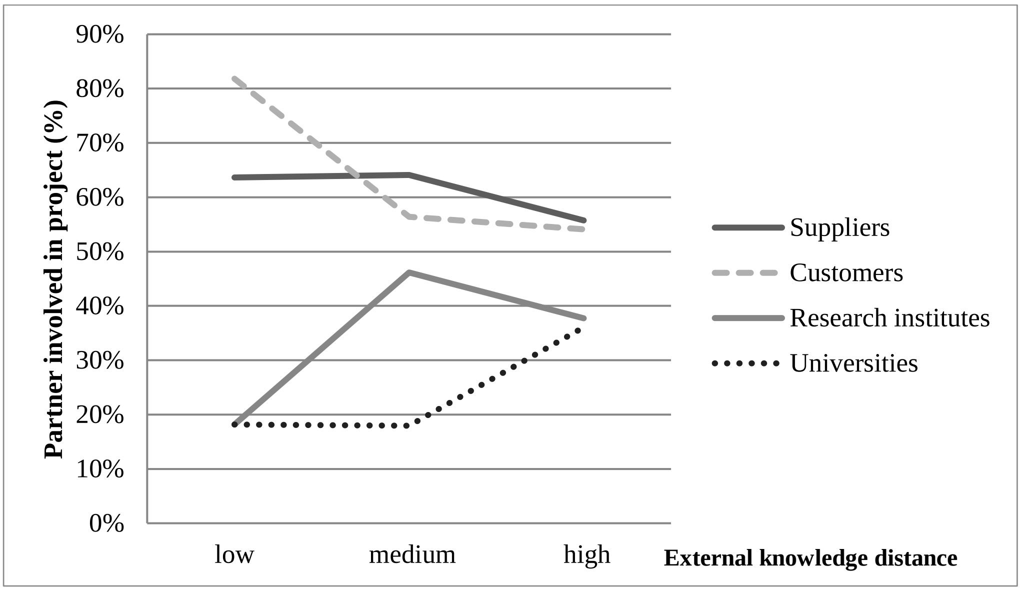


*Figure 17. Partner involvement versus external knowledge distance across 111 projects.*

From the structural model, the results show a significant and negative relationship between KD and PtM (STD β= -0.35, p<0.01), as predicted in H1. Additionally, H3 proposing a significant positive relationship between absorptive capacity and new product development performance was supported (STD β= 0.51, p<0.001).

Hypothesis 2 and 4 are less straight forward to answer from the analysis. In structural Model 1, in which we assumed a non-zero relationship for all variables, the model fit was lower, CFI 0.91. Coefficients STD β= -0.16 (not significant) is more than three times lower compared to the coefficient between ACAP and NPD performance STD β= .50. In the same structural Model 1, the relationship between ACAP and PtM, has a coefficient of STD β= -.05 (not significant) which is more than 6 times smaller compared to the coefficient between KD and PtM of STD β= -.32. This means hypothesis 2 and 4 are not invalidated. However, the confidence intervals of the two paths overlap partly in both cases and hence this model does not validate hypothesis 2 and 4 either.

In structural model 2, we assume that knowledge distance and the new product development performance is independent. Similarly, we assume that absorptive capacity might be largely independent on product to market. The coefficients between KD and PtM and between ACAP and NPD performance do not change in value or size but the structural model fit improves significantly: RSMEA = 0.026, CFI = 0.955, TLI = 0.946. While no conclusive proof either, this suggests that knowledge distance and NPD is indeed largely independent, same as ACAP and PtM. The hypothesis results are summarized in Table 20.

*Table 20*
*Hypothesis Results*

| Nr. | Hypothesis | Results |
| --- | --- | --- |
| H1 | Compared to projects with a higher perceived knowledge distance, projects with a lower knowledge distance have a higher chance that the outcome of the R&D project is to bring a product on the market | Hypothesis is supported. |
| H2 | A lower perceived knowledge distance is more strongly associated with whether or not the outcome of an R&D project is a product on the market than the level of absorptive capacity is. | Structural model 1 gives STD coefficients of -0.32, $p<0.01$ for KD and -0.05, non-significant, for ACAP. This suggests that KD was more strongly related with the outcome of an R&D project being a product to market, but there is an overlap in the confidence intervals and hence this hypothesis is not convincingly supported. Structural model 2 assumes no relationship between ACAP and product on the market. In this model the STD coefficient of knowledge distance becomes -0.35, $p<0.01$. The second model has a better model fit. |
| H3 | A higher absorptive capacity is associated with better NPD performance for projects with a product to market outcome | Hypothesis is supported. |
| H4 | Absorptive capacity is more a strongly associated with the NPD performance of projects with a product to market outcome than knowledge distance is. | Structural model 1 gives STD coefficients of -0.16, non-significant for KD and 0.50, $p<0.001$ for ACAP. This suggests that ACAP has a stronger effect, but there is an overlap in the confidence intervals and hence this hypothesis is not convincingly supported. Structural model 2 assumes no relationship between KD and NPD performance. In this model the STD coefficient of ACAP becomes 0.51, $p<0.001$, the second model has a better model fit than model 1. |

# Discussion

## Theoretical implications

Absorptive capacities enable firms to find and recognize relevant external knowledge sources and to be able to transform the external knowledge so that it can be assimilated with existing knowledge stocks (Cohen & Levinthal, 1990; Todorova & Durisin, 2007).Several studies have defined absorptive capacity as directly related to having internal R&D capacity and the kind of technical competencies that are available within the focal firm(Dyer & Singh, 1998; Murovec & Prodan, 2009; Rosenberg, 1990), while others suggest that radical innovation is more related to knowledge sharing capability and exploitative learning than the diversity of the internal knowledge base (Maes & Sels, 2014) much less dependent on internal R&D capacity. In this paper we join the line of thinking that more radical innovation, in terms of introducing new technology, is less dependent on the prior internal component competencies than it is on the internal absorptive capacity. While we agree that at least a fraction of new knowledge needs to be related to prior knowledge within the focal firm to be able to absorb the new knowledge (Cooper, 1994), we suggest, just as (Maes & Sels, 2014), that knowledge sharing capability and exploitative learning as we define it in our absorptive capacity definition is more important than a deep internal knowledge base when the innovation strategy of a company in a certain domain is based on close R&D partnering. The results of this exploratory study support the notion that companies use decision gates in their innovation process whenever they start new or follow-up R&D projects. They use their own estimate of their technical competencies and the perceived knowledge distance with the new technology, to select R&D partners and to decide on the purpose of the R&D project being pre-product (including feasibility, demonstrator and prototype development) or actual product development based on the perceived market and technical risks. Firms seem to only decide to start actual product development when see technical and market risks as being low enough. Basically this means that we should rethink the concept of knowledge distance in such a situation. It looks as if in the estimation of the remaining knowledge gap the focal firm does not only take the component competencies from themselves but also the component competencies from trusted partners into account. Hence either the focal firm themselves can bridge the knowledge gap by having the right technical competencies in-house or a trusted partner with the right technical competencies bridge the knowledge gap as long as the focal firm has enough absorptive capacity to assimilate and integrate the external technology in the product.

We suggest that in an environment where R&D partnering is omni-present, knowledge distance is much less related with the NPD performance of projects aimed at product development than absorptive capacity is. We believe that based on the notion of a gated innovation process that defines milestones necessary to move from feasibility to prototyping to actual product development projects, the mechanism of dealing with knowledge distance works differently than previously assumed. We argue that the perceived knowledge distance determines not only the type of R&D partners but also the type of R&D project. It influences whether an R&D project is designed to introduce a product to the market in the first place or is designed as a pre-product R&D project such as a feasibility or prototype study. R&D managers and teams are usually able to estimate the knowledge distance quite accurately as technical competence management is a standard practice in high tech organizations (Wagner & Hoegl, 2006; Wernerfelt, 1984). As opposed to the traditional saying that a higher knowledge distance, in general, reduces NPD performance, we propose an updated model that we outline in Figure 18, where we assume a gated innovation process and explicitly separate the pre-product development stages from the new product development stage. In the earlier pre-product development projects the development performance is dependent on the knowledge distance of the focal firm, the knowledge distance of the key partner(s) moderated by the absorptive capacity of the focal firm as well as the absorptive capacity of the focal firm in general. These pre-product development projects aim to reduce knowledge distance of the focal firm and/or reduce knowledge distance of key partner(s) and/or increase absorptive capacity of the focal firm. When the overall KD of the focal firm *and its key partners* is perceived to be low enough and integration of external knowledge is expected to succeed the actual product development project will start. In other words, the focal firm either fills up the knowledge gap or builds a bridge with one or more R&D partners to overcome the knowledge gap. As shown in this Chapter, the NPD itself is then largely dependent on the absorptive capacity of the focal firm, rather than the knowledge distance the focal firm sees itself confronted with. This model, which has to be further developed, explored and validated, could explain why some companies are excellent innovators without structurally reducing the knowledge distance with their partners below a certain point, as has been described in the case of close supplier relationships before (Bryan Jean et al., 2017; Chen, Lin, & Chang, 2009).

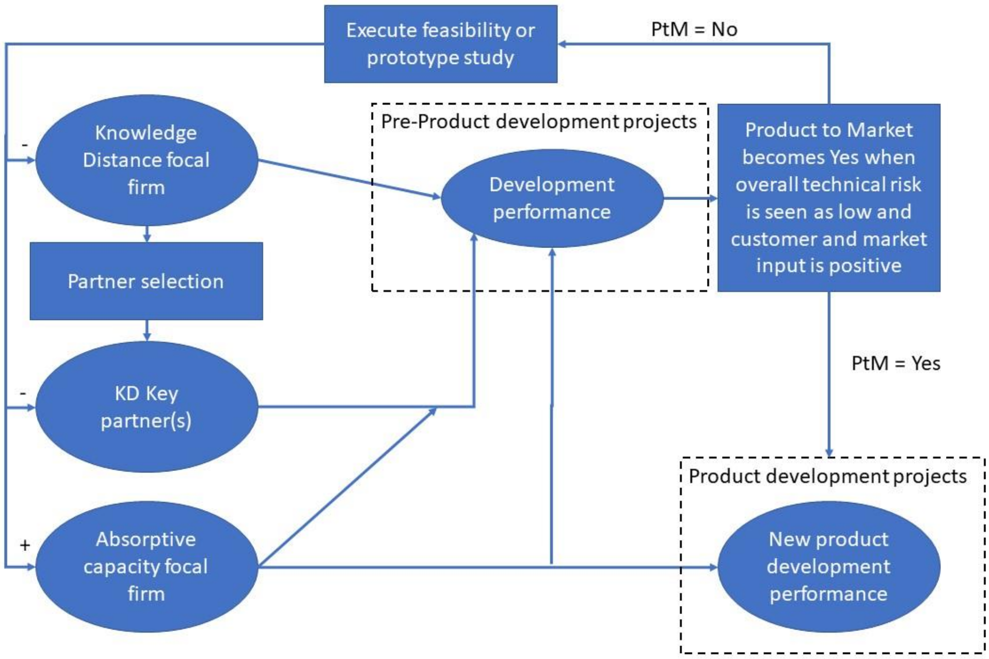


*Figure 18 Updated research model that assumes gated innovation process to decide on aim of R&D project*

This situation happens in industries that rely on frequent partnering, i.e., those that have strong vertical specialization like automotive and semiconductor industry, like those included in this study. We think that an iteration takes place in that either the knowledge distance is reduced internally or the faith in the external partner bridging the knowledge gap is increased to such an extent that it is possible to achieve the milestone of starting a project with the aim to bring a product to the market. We expect that there might be an exception in case of an initial very high knowledge distance.[5]

Our findings for industries with strong vertical specialization show that practitioners:

- Have a good idea of the knowledge and technology gaps in their new developments: they know quite well what their own R&D teams can and cannot do;
- Build long-term relationships with R&D partners and hence also know well what their R&D partner can and cannot do; reduce technical risk and establish the way of

[5] When the knowledge distance is higher a selected R&D partner, when trusted and strategic, is able to bridge the gap permanently. For a very high knowledge distance though, partner selection cannot be done efficiently as at least a fraction of new knowledge needs to be related to prior knowledge (Cooper, 1994). So when the knowledge gap is so high that it basically means the focal firm cannot select the right partner anymore, we assume that the focal firm will first try to reduce KD a little by doing a study, hiring an employee with prior knowledge in the field and/ or collaborating with a university or research organization. Without a fraction of the knowledge that you are looking for even a high level of absorptive capacity will not help you anymore to select the right R&D partner.

working with new partners by working on smaller projects first or having a backup solution at hand;

- Estimate formally or informally the perceived knowledge distance between their internal R&D team(s) and the external partner(s) at hand;
- Decide on the outcome of the R&D project, be it feasibility, prototyping, or actual product development, based on the perceived knowledge distance, technical uncertainties, and their (prior) working relationship with the external partner(s).

In all of the implications above, we have not mentioned absorptive capacity. Contrary to the knowledge distance, the author's experience is that companies are often not explicitly aware of their own absorptive capacity. The decision of whether a product has to come to market is based on market and customer input as well as foreseen technical risks, but most companies do not assess their own absorptive capacity as a part of the decision process to go to market. Hence, limitations in absorptive capacity are rarely, if ever, seen as a deal breaker.

Therefore, we were not surprised that in this paper, we found that once companies move into actual product development, the new product development performance becomes dependent mainly on absorptive capacity instead of the knowledge distance. In case of low knowledge distance, this is inevitable while in case of a higher remaining knowledge distance, a validated R&D partner bridges the knowledge distance gap.

Many studies have linked absorptive capacity predominantly to the R&D activities of firms (Veugelers, 1997; Zahra & Hayton, 2008) under the assumption that internal R&D competencies allow a firm to recognize external trends and developments in technology and to evaluate them correctly. We like to join the critics of this idea and suggest that internal R&D capacity and external knowledge sourcing practice are in fact two complementary skills (Ebersberger & Herstad, 2011; Schmiedeberg, 2008) rather than substitutes (Chesbrough, 2006). A higher perceived knowledge distance and hence lower internal R&D capacity in a certain domain does not imply that the company is less equipped to benefit from external knowledge sourcing than a firm with low knowledge distance and high internal R&D capacity in a certain field. Having a high absorptive capacity and collaborating with the right partners means that much less technical competence in a specific area is needed in-house to still achieve outstanding NPD performance. Once a product development project aimed at bringing a product to the market starts, absorptive capacity becomes the main determinant of the quality and speed of the new product development performance executed with partners. With that, the results of the study support the suggestion that absorptive capacity, as a part of architectural competencies, is more independent to knowledge distance (and with that the component competence of internal R&D teams) than described in prior literature (Cooper, 1994; Veugelers, 1997; Zahra & Hayton, 2008). The finding that the new product development performance in terms of speed and quality depends on absorptive capacity rather than the knowledge distance itself has important implications. While Zander and Kogut (1995) found that specifically codifiability, teachability, and parallel developments are important aspects that increase the speed of transfer of new technologies, this research suggests that absorptive capacity of a company will increase the new product development speed & quality independently of the competence of the internal R&D team in a certain technology field. Complementing Zander and Kogut's (Zander & Kogut, 1995) view of companies as social communities for the creation and communication of knowledge, absorptive capacity can be seen as the ability of a company to look beyond its own borders to find and form social communities for the creation and communication of knowledge within a partnership alliance.

## Limitations and future research

Several limitations have to be considered when interpreting the results of this study. First, the results are based on self-reports, and even though measures have been taken to avoid a bias by including only the last finalized projects as well as making sure that neither positive nor negative reporting had any consequences for the reporter, the outcomes of the study, while being much more quantitative compared to the extant innovation literature, are still based on individual opinions rather than standardized facts of performance in the market.

Second, the practicalities of collecting detailed data from one project limited the size of our sample, meaning that we could not compensate for many contingent factors. The identified relationships should be confirmed by conducting additional interviews with semiconductor executives.

Third, all data on the R&D project performance have been collected on one side of the dyadic relationship, the company that develops the end-product.

Fourth, we are assuming that partnerships are a one-way street, in the sense that our focal firm is in charge of initiating projects and inviting partners. This is not always the case though. NPD projects may be adapted once negotiations with a partner start.

Fifth, the relationship between especially knowledge distance and effectiveness of partner selection potentially could be non-linear. One can imagine that there is an optimal between a low knowledge distance and a high knowledge distance when bridging a knowledge gap with R&D partners. By means of linear regression we have checked for a potential parabolic relationship and have not been able find one.

Lastly, the data were obtained from a homogenous group of companies in the semiconductor industry, an industry which invests a high percentage of company turnover in R&D and were working with alliances is the norm rather than an exception. It would be interesting to see similarities and differences between low R&D companies. This would further validate the idea that architectural competencies (Henderson & Cockburn, 1994), one part of which is absorptive capacity, are more independent to component competencies, one part of which are technical competencies of internal R&D teams. It would be further worthy to study companies that are integrators and which have almost no component competencies for different technology, except for system engineering and the knowledge of how to integrate and productize most effectively.

Future study should further investigate how the use of a gated innovation process reduces the need for internal R&D competencies in some domains once sufficient absorptive capacity and a strong R&D partnership are in place. Our results pinpointed a significant relationship between external knowledge use strategy (being recombination versus replication and internal) and the knowledge distance, and further studies could clarify this finding. Are R&D teams in fact aware of the knowledge distance and do they decide to recombine more often when the knowledge distance is larger? Alternatively, is it the other way around and do R&D teams that are not so capable of dealing with recombination never choose to do R&D projects where the knowledge distance is high and turn instead to pre-development projects that allow them to build internal competencies and bridge the knowledge distance gap prior to actual product development?

Future research could also exploit the role and importance of different partners much more. In this study, we considered only the participation of partners, but it is likely that different partners play a different role and that this role differs according to the knowledge distance and expected R&D outcome at hand. This study assumed that R&D teams have a better and more explicit understanding of their own technical competencies than they have of their own absorptive capacity. Further study is needed to validate or reject this assumption.

## Managerial implications

The notion that absorptive capacity and knowledge distance, or the opposite of internal R&D technical competencies in the focus area of the project, are more independent than previously assumed has important management implications. It means that the old adagio of investing in internal R&D per se is neither sufficient nor always optimal for having an advantage in new product development performance. Instead, organizations have to make specific investments and adaptations to increase absorptive capacity over a wide range of technologies potentially relevant for (future) business. Investing in absorptive capacity is an expensive endeavor but with enormous benefits for diffusion and dissemination of (new) ideas and technology within the organization. An internal R&D organization with top technical specialists risks that these specialists will not seek outside knowledge, and even if they consider it, they may quickly want to dismiss ideas that do not fit their norm or current innovation pipeline. Organizations must hence find ways to not only celebrate top technical specialists but celebrate also people with an outside perspective who challenge current thinking and contribute to more radical, breakthrough, and disruptive innovation by introducing new, more radical ideas and technology into the organization. This has great implications for companies that want to benefit from open innovation. It means that they should hire employees with a different profile than the traditional internal top specialist or train them internally. The R&D organization should be set up by management in such a way to have greater access to new sources of knowledge. To benefit fully from outside ideas, management should make enough time available to discuss emerging innovation concepts rather than optimize the innovation pipeline too strictly.

## Conclusions

We proposed a model to investigate how knowledge distance and absorptive capacity relate with the aim and performance of new product development projects that integrate new technology. We argue that the type of partners selected, and the intended outcome of R&D projects are based mainly on the perceived technical competencies of the external partner and the knowledge distance with the internal R&D team. Because of a stage-gate innovation process, a high knowledge distance is usually reduced either by building up internal technical competencies through working with a university or research institute (bridging the knowledge distance) or by building integrative competencies, for example, by working with a supplier with the aim is to reduce only the knowledge distance at the interface but not the knowledge distance with the new technology per se so that the integration can be done fast and without too much risk (which is eased by high absorptive capacity). True product development with the intention to bring a product to the market will start only when one of these conditions is met. We found that absorptive capacity and not knowledge distance dictates the new product development performance in terms of speed and quality when bringing a product to the market. Whereas previous studies have defined technical competencies and absorptive capacity as complementary assets, we found these to be more independent. More absorptive capacity is positively influencing NPD performance, rather independent of the knowledge distance. However, the project collaboration partners are chosen based on the knowledge distance the R&D team sees itself confronted with rather than its absorptive capacity. Depending on the innovation approach and phase, both types of organizational competencies are needed or one of them can be much more needed than the other. In case of internal developments only, technical competencies are of course dominant while in case of being a fast follower that integrates rather than innovates, a high absorptive capacity with low competencies in individual technologies can also work well. Our findings offer support to innovation managers by showing that both internal R&D component competencies and architectural competencies, including absorptive capacity, require appropriate attention and support in terms of organizational processes, HR, and financial support.

## Acknowledgments

This study is based on data which was collected during a study done with professor Carla Koen and whose insights have helped a lot to gain insights for this study. The initial questionnaire was created by Thijs Peeters as a part of his Ph.D. work (Peeters, 2013), and with his kind permission, it has been adapted for this study. Inger Rempt transformed the questionnaire into a visibly pleasing web questionnaire, which expedited the data collection because Olfa Marzouk merged all address databases so that the questionnaire could be sent to many semiconductor professionals at once. I am grateful to both for their practical help. Finally, I thank the executive management from Imec for their support.

# Appendix 1: Definitions, parameters, and sources of questions

| D# | Parameter | Construct | Answer type | Source | Original construct |
|---|---|---|---|---|---|
| | Name | What is the name of the company you work for? | Open | | |
| | Respondent Background | What is your function area? | Multiple options +open | | |
| | Respondent experience | For how long have you been working in your current position? | 0-1 years<br>1-3 years<br>3-6 years<br>6-10 years<br>Over 10 years | | |
| | Respondent experience | For how long have you been working in this industry? | 0-1 years<br>1-3 years<br>3-6 years<br>6-10 years<br>Over 10 years | | |
| **PtM** | Product | The project lead to a product which came available to the market | Y/N | | |
| | Product | if Y: what is the product number? | Open (number from catalogue), customer specific | | |
| | Product | If Y: what was the date of introduction? | Open | | |
| | Product | If Y: what was the main purpose of adding this product to your company's portfolio? | Multiple options+ multiple answers possible: lead customer requested development, competitors already had a solution we needed to have one too, improved product in existing market, improved product in developing market, complete new product in existing market, complete new product in new market +open | | |
| **C1**<br>**C2** | Product | *If Y:* To which degree do the following two statements fit the product?<br>1. The quality of the product is clearly better than other alternatives on the market<br>2. The product was introduced on the market at the planned timing | Likert scale from 1 to 7, "Strongly Disagree" to "Strongly agree", include don't know | (Praest Knudsen & Bøtker Mortensen, 2011) | Original construct, but added "don't know" |
| **C3-**<br>**C8** | Product | This product development has overall | Likert scale from 1 to 7, "Strongly Disagree" to | (Praest Knudsen & Bøtker Mortensen, 2011) | Original construct, 7-point semantic scale; statements are given the value 1 |

| | | | | | |
|---|---|---|---|---|---|
| | | Speed: been slower/faster than the norm in the industry<br>Been slower/faster than our expectation<br>Been slower/faster than a typical product development project in our firm<br>Cost: had higher cost compared to the norm in the industry<br>Had higher cost than our expectation<br>Had higher cost than a typical product development project in our firm | "Strongly agree", include don't know | | through 7 is changed to a Likert scale and added "don't know" |
| | New technology | This project contained technology new to our company | Y/N | | New questions in this questionnaire, needed to identify if new technology is used and if so what kind of new technology. |
| | New technology | If Y: please fill in new to the world technology/ new to this market technology/ new to our company and still developing in the world /new to our company but mature in other products/ | | | |
| **EKUS** | New technology | If Y: please fill in: we mainly developed the technology internally; we developed the new technology by receiving it from a partner making little changes, we developed the new technology by receiving it from a partner but significantly altering it, we co-created it with a partner, we mainly developed the new technology based on publicly available technology (for example open source software) | | | New question to identify if new technology has been developed mainly internally or externally. |
| | Participation | Who has participated in the NPD process?<br>*Internal sources:* Employees with daily attachment to product development and R&D; Employees without daily | Y/N, how many + Multiple answers possible | (Praest Knudsen & Bøtker Mortensen, 2011) | Original construct, but deleted other employees in headquarters or subsidiaries (not orthogonal on either two answers) split universities and research institutions. |

| | | | | | |
|---|---|---|---|---|---|
| | | attachment to product development and R&D *External sources:* Suppliers, Customers, Universities, Research institutions, Consultant, Competitor, Other | | | |
| | Participation | If yes to universities and/or research institutions, please fill in which one(s) | List of options + other, please fill in | | |
| | Participation | Who was the most **Key partner** in the new product development project (only one answer) | One answer only sees 3.1 + other, please fill in | (Praest Knudsen & Bøtker Mortensen, 2011) | Original construct, but split universities and research institutions |
| | Participation | *Branch, only when external partner mentioned:* When most important partner was external, how satisfied were you with the cooperation? | 7 point Likert scale: 1 completely unsatisfied; 7 completely satisfied | | |
| | Participation | *Branch, only when external partner mentioned* For how many years are you collaborating with this partner already? | 0-2 years; 3-5 years; 5-10 years; more than 10 years | | |
| | Project size | How many people (in Full-time Equivalent, FTE) have been working on this project on its peak? | Number – specific | | |
| | Deadline | The main deliverables were on-time. | Likert 1-7, Strongly disagree to Strongly agree | | |
| | Deadline | If Y on product on market: the product was on the market at the planned volume production date | Likert 1-7, Strongly disagree to Strongly agree | | |
| | Knowledge distance | *Branch: Answer only when yes to question 2.1.: Please answer the following questions on the new technology/knowledge used in the project* | | | |
| KD0 | Knowledge distance | To independently develop this new technology by our team, highly trained personnel would need to be hired. | Likert 1-7, Strongly disagree to Strongly agree | (Steensma & Corley, 2001) | Measuring *relatedness:* The extent to which the firm would need to have invested in trained personnel and equipment for independent development as well as the relative cost of such development to independently develop this knowledge, highly trained personnel would need to be hired. |

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| **KD1** | Knowledge distance | Little new investment in equipment or staff would be required of our firm to independently develop this technology. | Likert 1-7, Strongly disagree to Strongly agree | (Steensma & Corley, 2001) | Measuring *relatedness:* The extent to which the firm would need to have invested in trained personnel and equipment for independent development as well as the relative cost of such development. **Small new investment in equipment would be required for our firm to develop this technology independently.** |
| **KD2** | Knowledge Distance | The cost to develop this technology independently would be greater than our previous development efforts | Likert 1-7, Strongly disagree to Strongly agree | (Steensma & Corley, 2001) | |
| **KD3** | Knowledge Distance | The TOTAL cost to develop this technology within our firm would have been significantly greater as compared to the average cost of other technologies that our firm has independently developed in the past | Likert 1-7, Strongly disagree to Strongly agree | (Steensma & Corley, 2001) | |
| | Uniqueness of novelty | *Branch: Answer only when yes to question 2.1.: Please answer the following questions on the new technology/knowledge used in the project* | | | |
| | Uniqueness of novelty | Many of our competitors had fundamentally similar technology. | Likert 1-7 | (Steensma & Corley, 2001) | Measuring *uniqueness*: The current prevalence [of the technology] within the industry. **Many of our competitors had fundamentally similar technology.** |
| | Uniqueness of novelty | A limited number of organizations in our industry possessed this technology. | Likert 1-7 | (Steensma & Corley, 2001) | Measuring *uniqueness*: The current prevalence [of the technology] within the industry. **A limited number of organizations possessed this technology.** |
| | Uniqueness of novelty | Few credible substitutes competed with this technology. | Likert 1-7 | (Steensma & Corley, 2001) | Measuring *uniqueness*: The current prevalence [of the technology] within the industry. **Few credible substitutes competed with this technology.** |
| | Uniqueness of novelty | This specific technology was common within the industry. | Likert 1-7 | (Steensma & Corley, 2001) | Measuring *uniqueness*: The current prevalence [of the technology] within the |

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| | | | | | industry. **This specific technology was common within the industry.** |
| | External knowledge decision criteria *(part of identification?)* | *Branch: Answer only when yes to question 2.1.: Please answer the following questions on the new technology/knowledge used in the project* | | | |
| | External knowledge decision criteria | We thoroughly investigated all options to get access to this technology, | 1 – not at all, 7 very much | | |
| | External knowledge decision criteria | Both internal development and external gathering were given equal attention when searching for technology. | Likert 1-7 | | |
| | External knowledge decision criteria | What were the decision criteria (please select all that apply)? | Options: build internal competence for future, lowest overall cost, highest product performance, shortest time to market, no internal resources available+ other (open) | (Rechtin & Maier, 1997) | |
| | External knowledge decision criteria | What was the single most important criteria? Select only one | Options: build internal competence for future, lowest overall cost, highest product performance, shortest time to market, no internal resources available+ other (open) | (Rechtin & Maier, 1997) | |
| | Absorptive capacity | ***Please answer these questions in general for your company (14 -17)*** | | | |
| **I0** | Identification | We frequently scan the environment for new technologies. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *recognize:* Captures a firm's activities of environmental scanning and monitoring. Moreover, it measures the examination of industry information and the observation of external knowledge sources. **We frequently scan the environment for new technologies.** |
| **I1** | Identification | We thoroughly observe technological trends. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *recognize:* Captures a firm's activities of environmental scanning and monitoring. Moreover, it measures the examination of industry information and the observation of external knowledge sources. **We thoroughly observe technological trends.** |

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| **I2** | Identification | We observe in detail external sources of new technologies. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *recognize:* Captures a firm's activities of environmental scanning and monitoring. Moreover, it measures the examination of industry information and the observation of external knowledge sources. **We observe in detail external sources of new technologies.** |
| **I3** | Assimilation | We regularly match new technologies with ideas for new products. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *transmute:* Captures a firm's proficiency in combining new and existing knowledge. In addition, it addresses the matching of technologies with new product ideas. **We regularly match new technologies with ideas for new products.** |
| **I4** | Exploitation | We quickly apply internally developed technology in new products | Likert 1-7, Strongly disagree to Strongly agree | | |
| **I5** | Exploitation | We easily implement acquired technology in new products. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *transmute:* Captures a firm's proficiency in combining new and existing knowledge. In addition, it addresses the matching of technologies with new product ideas. **We easily implement technologies in new products.** |
| **I6** | Exploitation | It is not well known who can best exploit newly developed technologies inside our firm. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *transmute:* Captures a firm's proficiency in combining new and existing knowledge. In addition, it addresses the matching of technologies with new product ideas. **It is well known who can best exploit new technologies inside our firm.** |
| **I7** | Transformation | We thoroughly maintain relevant technology and/or knowledge over time. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *Transformation* \| *Maintain*: Activities of retaining and storing knowledge. Moreover, it addresses knowledge sharing and communication within a firm. **We thoroughly maintain relevant knowledge over time.** |

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| **I8** | Transformation | We communicate relevant technology developments across the units of our firm. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *Transformation \| Maintain*: Activities of retaining and storing knowledge. Moreover, it addresses knowledge sharing and communication within a firm. **We communicate relevant knowledge across the units of our firm.** |
| **I9** | Transformation | We are proficient in reactivating existing knowledge for new uses. | Likert 1-7, Strongly disagree to Strongly agree | (Lichtenthaler, 2009) | Measuring *Transformation \| Reactivate*: Whether a firm can quickly react to opportunities by relying on its existing knowledge. Furthermore, it measures a firm's proficiency in addressing environmental changes by reactivating its knowledge. **We are proficient in reactivating existing knowledge for new uses.** |

# Chapter 5
# Main findings and conclusions

Collaboration with external Research and development (R&D) partners in New product development (NPD) can be an enduring source of competitive advantage (Cassiman & Veugelers, 2006). In many collaborations however, the innovation results are disappointing (Eisenhardt & Martin, 2000) or just not as good as expected(Dyer et al., 2001; Eisenhardt & Martin, 2000; Expósito-Langa et al., 2011). Hence the ability to apply R&D partnering successfully is a must for every business unit individually and for companies as a whole. This thesis examined how organizational competencies and the firm's prime R&D objective for the R&D project at hand are related with R&D partner choice and, more importantly, NPD performance at the project level. The individual papers make the following contributions.

The first essay (Chapter 2) - *Customer is King, but when to bow to a supplier?: most important partner selection in new product development*, I uncover the mechanics that make a customer or a supplier the most important partner (MIP) in terms of being able to change the product specification instead of a party internal to the focal firm. An extensive literature on R&D partnerships (e.g., (Kesteloot & Veugelers, 1995; Lhuillery & Pfister, 2009; Schmiedeberg, 2008) has dealt with many issues, including the partner selection process but none of them has addressed which partner becomes dominant for the product specification in case of multiple R&D partners. In practice, an organization typically has multiple R&D partners, including internal R&D in complex NPD (Cassiman & Veugelers, 2002; Morgan & Berthon, 2008). This paper contributes to Resource Dependence Theory (Hillman et al., 2009; Pfeffer & Salancik, 1978)(RDT) literature with the concept of the MIP for product specification. It provides initial validation of how knowledge distance, external knowledge usage, and the R&D prime objective of the focal firm are related with who they see as MIP. In an RDT view firms are constrained by and depend on other organizations that control resources that are critical for them according to the view. This is certainly the case in the environment investigated in this thesis where R&D partnering is omni-present. Following the logic of RDT, Li and Atuahene-Gima (2001) maintain that the success of a firm's innovation strategies depends on perceived environmental conditions and relationship-based strategies. That is, firms try to enhance their innovative capability to respond to environmental changes and cope with dynamic relationship structures.

The explication of MIP adds to and expands RDT with a clarification on how and when an external R&D partner gains importance as part of the struggle to enhance the firm's innovative capability. Who is seen as MIP is based on the focal firm's prior organizational competencies, specifically its technical competencies and external knowledge use and the R&D prime objective for the project at hand. The results show that these three characteristics of the focal firm explain differences between the most important partner and the other partners, where the R&D prime objective and prior technical competencies change the outcome of the decision process. That is, it is shown that the decision process is based more on a complex trade-off that is part of the firm's attempt to manage uncertainty and mitigate the effects of external forces in order to enhance their performance rather than on "who pays," as is normally assumed in cost economics. The second contribution of the paper to the literature on outsourcing and partner selection is that customers do not become the MIP in just any situation, even though they often are the paymaster for the focal firm. Earlier and stronger involvement of a customer is noted when they contribute not only to the requirements but also to the R&D prime objective (in line with (Campbell & Cooper, 1999)). When the knowledge distance is higher, a lead customer, as the MIP, can speed up product development and reduce market risks. A supplier might be seen as MIP when the R&D prime objective focuses on the highest product performance and the supplier's technology is so unique and dominant that it significantly improves the performance of the final product. Then they should be integrated fully and early in the development process as already described by Handfield (Handfield, Ragatz, Petersen, & Monczka, 1999). On the contrary, when the aim of the innovation is the lowest cost, the focal firm itself usually remains the MIP. Throughout the paper, I use the assumptions found in the BDT of bounded rationality, namely satisfying instead of maximizing (Cyert & March, 1992) and rule-based behavior of the decision makers at the focal firm in times of uncertainty.

The second essay (Chapter 3) - Chapter 3 titled *Close collaboration matters: Relating organizational competencies with external knowledge transfer and use* uncovers an interaction effect between organizational architectural and component competencies, which have been seen mainly as independent aspects in the literature thus far (Cockburn & Henderson, 1998; Henderson & Cockburn, 1994). Many researchers have suggested that internal R&D and external knowledge sourcing are complementary activities (Cassiman & Veugelers, 2006), but more recently there is more attention to the idea that replacing internal R&D with external R&D sourcing activities to optimize innovation performance only works up to a certain level (Berchicci, 2013). For a part this has to do with opportunity cost of opening up and the fact that there is less to learn from external parties when there is great internal technical competency in a certain field available within the focal firm, but for a part this also comes from the fact that negative attitudes towards external collaboration prevail. In this essay I show that architectural competencies, specifically the communication aspect of wider and more frequent interaction and the ability to recombine helps to overcome that less external knowledge is absorbed when teams are more technically competent themselves prior to the start of an R&D collaboration with a research organization (Dyer et al., 2001; Witzeman et al., 2006). The findings are in line with Mortara and Minshall (2011) who suggested that an organizational culture, which is more ready to accept ideas from outside and to take risks, may have a greater effect on the adoption of open innovation than the firm's specific innovation needs and strategy. This essay adds to the resource-based view (RBV) literature by introducing a resource-based model, which also helps explain unexpected (negative) results of previous studies on the outcomes of open innovation. It does this by starting with separate effects of component and architectural competencies, as done in the previous literature, but subsequently taking into account their interactive effect. This interaction effect explains the puzzling and sometimes contradictory results in terms of component competencies found in previous papers (Burcharth et al., 2014; Katz & Allen, 1982; Praest Knudsen & Bøtker Mortensen, 2011), specifically when there is a knowledgeable R&D team prior to the collaboration. Although a knowledgeable R&D team can build and transfer knowledge from one or more external partners very effectively, as in an open innovation environment, the outcome may sometimes be much worse than expected (Eisenhardt & Martin, 2000; Praest Knudsen & Bøtker Mortensen, 2011). When the R&D team already has knowledge in the area and there is little interaction during the project with the external R&D team and/or no recombination, I find that the post-project innovation outcome suffers dramatically. Like earlier papers (Kerssens-van Drongelen & Bilderbeek, 1999; Zander & Kogut, 1995), I found evidence that more widespread and frequent interaction between personnel from both sides as well as within the focal firm leads to a better transfer. Strong interaction between the firm and research partner as well as recombination are the most important drivers to improve the post-project innovation outcome. At the same time, the results support that having integrated teams, i.e. an R&D team which physically embeds R&D personnel from the focal firm, is strongly (positively) associated with the transfer of knowledge and the chances of success. Previous studies (Collins & Hitt, 2006; Martin & Salomon, 2003; Martin et al., 2010) have already shown that due to its nature, tacit knowledge has a higher potential to create a distinctive competitive position compared to explicit knowledge, and integrated R&D teams can greatly reduce the barrier of non-tacit knowledge transfer, hence increasing the innovation performance. This study adds to these studies by showing that integrated R&D teams also lower tacit knowledge transfer barriers. What is important to notice here is that these parameters in fact might not be fully independent. Companies that have better practices in place to do knowledge transfer understand better that close collaboration is the key, and an integrated R&D team is an effective way to force this close collaboration. Hence, companies with higher architectural competencies might also choose more often to send residents to join physically and fully integrate with the external R&D team for a longer period of time. This study is inconclusive in this aspect.

In the third exploratory essay (Chapter 4)- *Fill up the knowledge gap or build a bridge: knowledge distance and absorptive capacity* I argue that absorptive capacity is, in fact, largely independent to internal technical competencies (where knowledge distance is a reverse indication of) with respect to its effect on NPD performance, a finding that differs from what is described in prior literature (Veugelers, 1997; Zahra & Hayton, 2008). A more recent publication by Som, Kirner, and Jäger (2015), which found little difference between high-intensive R&D and low-intensive R&D in terms of absorptive capacity of new knowledge, is to some extent in line with this finding. Rosenkopf and Almeida (Rosenkopf & Almeida, 2003) found that when a firm creates an alliance, it is just as likely to learn from technologically dissimilar firms as from similar firms. This study looked into knowledge distance, which depends on the component competencies of the company prior to the R&D project and absorptive capability. Absorptive capacity (ACAP) can be seen as the architectural competence that influences the creation of other organizational competencies (Zahra & George, 2002). By adding the perspective of a stage-gate innovation model, which is used in almost all high tech, pharma, and automotive industry, I theorized that companies decide only to start actual product development if the technical readiness level they perceive for the focal firm together with its selected partners is high enough. As long as the technical readiness level is lower, they will do R&D projects not with the aim of product development but with the main aim to e.g. build-up competence, do a feasibility study, or prototyping. The study confirmed that ACAP is influencing final NPD performance in a positive way, independent of the knowledge distance that remains. I end the Chapter with an updated research model which uses the milestones as assumed with a stage-gated innovation process within the company to decide on the aim of the R&D project at hand, being competency build-up, feasibility, prototyping or actual product development.

This dissertation is unique in the fact that it looks at R&D partnerships and innovation performance at the project level. The project level is not often investigated and when it is investigated, it is often taken as a firm's internal view only, and hence based on RBV theory. The uniqueness of this thesis is that it looks at the project level in not only firm internal behavior but also into the external behavior where the power of external R&D partners is directly linked to the dependency the focal firm has on them, hence enhancing RBV theory with relevant aspects from RDT.

If we look at the overall model investigated in this thesis with the main effects as shown in Figure 19, it ties together these two theories which have been developed independently but that come together in an environment of open innovation and extensive R&D partnering.

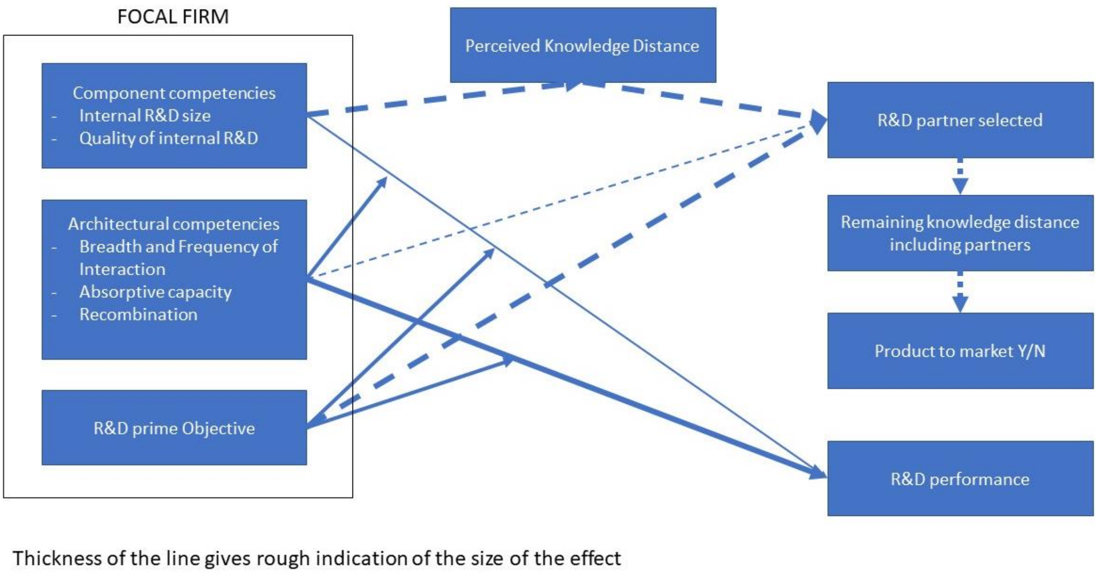


*Figure 19. Overall model with main effects discussed in this thesis*

This dissertation as a whole contributes to the innovation and management strategy literature with an expanded RBV of the firm that integrates important aspects of RDT and hence expands RBV to include some aspects outside the own firm's boundaries. RBV says that innovativeness is a valuable resource that enhances a firm's competitive advantage (Menguc & Auh, 2006) and explains innovative performance differences between firms in relation to *internal or firm-level factors* (Wernerfelt, 1984). In RBV, intangible resources are of focal concern when examining the factors that account for performance variation (Galbreath, 2006). In this thesis, I provide valuable insights by modeling architectural competencies (also called dynamic capabilities and including absorptive capacity) and component (including all technical) competencies as described by (Cockburn & Henderson, 1998; Eisenhardt & Martin, 2000; Henderson & Cockburn, 1994; Teece, 2007) with a direct and interaction effect. We empirically validate their relationship with partner selection and innovation performance at the project level in Chapter 3. RDT (Hillman et al., 2009; Pfeffer & Salancik, 1978) on the other hand focuses on *external firm factors* and explains that firms are constrained and depend on other organizations that control resources that are critical for them. In Chapter 2 I use this theory to explain under what circumstances an external R&D partner may gain power and dominance, is seen as the MIP and become critical amongst others for the product specification. When we combine this, we are basically expanding the RBV to include the organizational competencies, especially the component competencies, of key partners, i.e. a critical supplier or key customer as if they were existing at focal firm-level. The behavior of the focal firm in case of a critical supplier or key customer is as if the company boundaries are diminished, early involvement in the product development cycle of these critical partners, sharing of roadmaps and intimately working together to share tacit as well as in-tacit knowledge and routines are part of these critical partnerships. This has been described and recognized in earlier literature about critical suppliers in new product development (Handfield et al., 1999; Traitler, Watzke, & Saguy, 2011; Wagner & Hoegl, 2006) as well as key customers (Campbell & Cooper, 1999; Homburg, 2000).

In the more experimental Chapter 4 I basically confirm this idea of an RBV of the focal firm to expanded with RDT and as such using the component competencies of the critical R&D partner(s) as if they were internal to the focal firm, when I show that NPD performance, as defined by the product development speed and quality, is mainly dependent on ACAP in an R&D environment which assumes a form of gated innovation process and omni-present R&D partnering possibilities. In this Chapter, we notice that an explicit gated innovation process is standard practice in nearly all high tech companies, just as component competence management is and that this aspect has been overlooked in much of the literature on organization competencies. When I step back and look at the impact of this active innovation management, I see that it is mainly aimed at reducing technical and market risks sufficiently before actual product development starts by having pre-product development projects that focus on e.g. feasibility, proof of concept or prototyping. What we see is that the remaining knowledge distance taken into account on the basis of which the decision is taken to start actual product development is not only based upon the component competencies of the focal firm's R&D teams but includes the component competencies of one or more trusted partners. I believe this has become the standard in a field where external partnering has become so common as the high tech industry. I showed that the choice of partners and the outcome of the R&D project being feasibility, prototyping or product development is dependent on the perceived KD because the focal firm in the lead of partner selection will work with or exclude certain (type of) partners depending on whether the knowledge distance is higher or lower. The actual NPD performance once product development actually starts however, is largely dependent on absorptive capacity of the focal firm as either the focal firm's own component competencies are high enough or they have found a reliable partner, with the right component competencies, to bridge the remaining knowledge gap. It ties together with the results from Chapter 2, where I explain under what circumstances a critical partner, being a customer or supplier can be seen as the most important partner, rather than the focal firm itself. In Chapter 4 we see that such a partner's component competencies are taken into account as if it were the component competencies of the focal firm itself, as long as the focal firm has enough trust in this partner and absorptive capacity to use this external knowledge efficiently in their product. The results of Chapter 4 also tie together with the results we found in Chapter 3, in that the actual innovation performance when working with an external R&D partner much more relies on architectural competencies than it relies on the component competencies of the focal firm prior to the R&D project start.

We have to add a major constraint to this expanded RBV model which includes usage of the component competencies of its key partners as if it is the focal firm's own. Complete freedom of selection and usage of partners is severely limited in practice by *bounded rationality* (Griffith & Harvey, 2004). The decision-makers of the focal firm will consider only a limited set of elements at any given time, and they do not have the complete information available. Faced with the uncertainties of an incomplete market, (potential) partner, and technical information, the strategic partnership decisions will be rule-based (Gomes-Casseres, 1997). Besides this, the decision makers will use other simple rules to guide its behavior. "Not changing a winning team," i.e., using an existing coalition of R&D partners that have fulfilled the objectives in a similar prior R&D project, can be an example of such a simple rule.

This thesis also shows and gives more focus on how partner selection depends on the ex-ante aims of R&D projects. As the stage-gate innovation process is mostly used, the innovation stage based upon the technology readiness level in which a project falls greatly affects the partner choice; this has been overlooked by many researchers in current literature on partnership selection (Hagedoorn, 2002). The R&D prime objective in terms of internal competence build-up, highest product performance, time to market, or overall cost optimization will also relate with partner selection decisions and this has not been described in any prior literature as far as the author is aware. It basically ties the market strategies for sustainable competition of cost, differentiation and timing (Chesbrough, 2003; Chesbrough & Crowther, 2006; Porter et al., 1985) to partner selection (Dekker, 2008; Reuer & Devarakonda, 2017).

Finally, based on our findings, several strategies have been proposed for practicing managers, which can help develop limited architectural organizational competencies, overcoming the caveat of the "not-invented-here" and/or the "not-shared-here" syndrome (Agrawal et al., 2010; Antons & Piller, 2014; Eisenhardt & Martin, 2000) in their organization.

## Practical implications

Jointly, the thesis shows that the trade-off process that determines the MIP depends mainly on the perceived knowledge distance and recombination competence of the internal R&D combined with the R&D prime objective and the potential external partners. The innovation performance depends mainly on the component competencies of the R&D team when they don't partner. However, nowadays, as nearly every complex R&D project involves one and usually more than one R&D partner, innovation performance is largely dependent on the architectural competencies of the focal firm's team, including absorptive capacity, which is further aided when component competencies are also high. This, however, does not work the other way around, since high component competencies combined with low architectural competencies seems to be associated with non-optimal innovation performance when working with external R&D partners. This is a remarkable insight, as most practicing managers have an excellent idea of their team's component competencies, and they are able to improve them when necessary. On the other hand, they are much less proficient in estimating their team's architectural competencies, and many managers do not seem to know how to improve them. In a world of complex R&D, where R&D partnering is here to stay and will only become more dominant, the insight that architectural competencies (also called dynamic capabilities and including absorptive capacity), and not only component competencies are responsible for the innovation success, means that organizations and managers should spend ample time in creating an organization where enough attention is paid to building and maintaining architectural competencies at the organization, team, and individual levels. From a practical point of view, this means that organizations should hire and value people who can help the firm strengthen its dynamic capabilities, i.e., those with broad views who connect with others within and outside the organization, are open to new ideas and knowledge, and are able to communicate and make these new ideas and knowledge stick within their own organization, which can sometimes be at odds with deep technical specialization and straightforward R&D efficiency. Communication about and application of external knowledge takes a lot of time and effort. An integrated R&D team where people from different organizations have common objectives and work together to achieve a common goal can be a great way to reduce external knowledge transfer barriers, especially when there is much non-tacit knowledge. Of course, this comes at a cost. Component competencies should never be neglected, since organizations as well as individuals expand their knowledge base based on their prior knowledge. Individuals cannot be proficient in architectural competencies without having at least a bases of component competencies and a clear understanding of what technical competencies need to be added for future product developments. While this thesis evaluated what happens once the company decides on the R&D prime objective for a certain R&D project, to be able to decide on the strategy and to search for and evaluate potential partners, it is important for a company to develop at least a certain amount of component competence.

## Limitations and suggestions for future research

Notwithstanding its contribution, this dissertation also has several limitations. These limitations have already been addressed in each Chapter, but I mention the most important ones here.

### Endogeneity bias

The datasets used are unique and give an insight at project level variables, competencies and innovation outcome of collaborative R&D projects within the semiconductor industry that have never been reported before. The disadvantage of these special databases is that the response rate (in case of the questionnaire used in Chapter 2 and 4) and the amount of projects done within Imec (used in Chapter 3) is rather small and on top of that both datasets contain items of self-reporting. For the questionnaire used in Chapter 2 and 4, one of the biggest potential issues is *common method bias* (CMB), i.e., the variations in responses are caused by the instrument rather than by the actual predispositions of the respondents. By using, as much as possible, validated questions from earlier studies as well as doing multiple test-rounds of the questionnaire to refine the new questions, I intended to limit CMB. We guaranteed the anonymity of the respondents to avoid socially acceptable (positive) answers. We asked only to reflect on finalized projects to avoid the optimism bias

(Sharot, 2011) when still actively working on an activity. While we run the risk of *hindsight bias* by doing so, as people have the tendency to misremember earlier predictions and view what happened as inevitable. In this case though, I felt that the risk of optimism bias while still working on a project was a much higher risk as people cannot work on projects with high motivation if they don't believe in a positive outcome and hence they will overestimate the chances on a positive innovation outcome when the project is still on-going. The hindsight bias in this case is minimized as most questions referred to actual events that are well-documented (for example which partners were included, how much of the results of this project were used by the R&D partner and what was the R&D prime objective) and without any references which would indicate the anything that happened would be considered to be good, bad or inevitable. We also used predefined questions and measures as much as possible. Still, the state of this research field is such that some of these measures have not been made completely precise and fully tested in practice yet. Specifically this is true for the measures of knowledge distance and absorptive capacity (Liyanage & Barnard, 2003; Todorova & Durisin, 2007; Zahra & George, 2002). As far as the author is aware the measure itself as well as the measurement scale for absorptive capacity & knowledge distance has not been used in a similar environment before, i.e. high tech projects in the semiconductor industry. This results both in *less precise measurements* of the variables at hand as well as *measurement errors*. Specifically in Chapter 2, the original scale of knowledge distance, existing of 4 items, has been pruned and the item that asked about equipment investments has been removed, as with hindsight this cannot be seen as a good indication of knowledge distance in terms of especially choosing how much and how early to involve a customer. The resulting alpha is still only a mere 0.72 so measurement error is an issue here.

The dataset used in Chapters 2 and 4, based on a questionnaire about finalized projects in the semiconductor industry, was derived from experienced employees at higher levels within companies who have many experiences in their industry and hence can compare their latest project with previous projects. We collected data from June 19 until July 23 in 2013 and observed 235 responses, of which 111 are complete. About 50% of respondents discontinued after answering a few questions. The fact that most of the other respondents stopped answering the questionnaire quite quickly, together with a high level of experience of the people who did complete the questionnaire, gives us confidence that the right people have answered the questionnaire and that people who lacked expertise decided that the questionnaire was not for them and dropped out. Eighty percent of these respondents have worked in the semiconductor industry for more than ten years and thus have seen a considerable number of projects as a frame of reference. The size of projects they have worked on varied from very small (just one person) to very large (>1000 people and a $100M budget/year). The geographical response distribution of respondents was spread reasonably worldwide, with responses from all significant semiconductor areas of the world, i.e., Japan, Taiwan, Korea, America (includes Canada), and (Northern) Europe. Our belief in the accuracy of the results is supported by several studies that have shown that surveys with lower response rates often have more accurate measurements than surveys with higher response rates (Keeter et al., 2006; Visser et al., 1996).

It remains a limitation that it is not an independent assessment, but consists of *self-reporting* as the assessment is done by someone who was involved themselves in the project. We have however strived to check for the most important results that were self-reported by adding factual measurements and/or adding a second respondent. For example in Chapter 3, I have checked the overall evaluation which was self-reported in several manners. First I had more than one report of the overall evaluation and found the inter-rater reliability was very high, in more than 75% the answers were exactly the same, while in the remaining cases, the answers were very close (maximum 1 point difference on a 5-point Likert scale). In no case the business officer found a project successful while the technical officer found it unsuccessful, or the other way around. Second I checked the validity of this variable by linear regression of results used and patent application increase at focal firm which both turned out to be correlated in a highly statistically valid manner.

While the sample is unique in terms of involvement of companies from all over the world, large and small, the sample size of just over one hundred finalized projects is rather small.

All analyses have been done with a limited number of project specific variables and control variables and hence there is a risk of *omitted variables* confounding with independent variables. A limited number of project-specific control variables were introduced in the analysis of Chapter 2 and the same goes with the introduction of control variables in the analysis of the second database done in Chapter 3. Neither of these analyses gave any raise to a concern of unobserved project characteristics that might be confounded with the observed variables. In conclusion, for the findings of Chapter 2 and 4 it would be a great confirmation when the models would be replicated with a larger database. As such data is not easy to collect, another option would be to do feedback analysis or to create a comparable size database in another industry. Feedback analysis would strengthen the quantitative results, hence qualitative interviews with respondents from the companies included in this investigation could be used to confirm the results of this questionnaire study. As the questionnaire was administered only at one time-point, we cannot control for changes over time and thus we cannot establish cause and effect relationships.

In Chapter 3, I used another unique dataset, namely all projects done by one Imec division over the last ten years, which allowed us to compare the receivers of external knowledge quite fairly, as the transmitter is always the same group of people. Nevertheless, *self-selection and unobserved variables* are again a potential bias here. The fact that a partner decides to work with Imec is an explicit decision and the outcome of a search and negotiation process. I think it is fair to assume that in most cases, only internal research or research conducted with another research center was the alternative for this particular set of projects. The fact that the company partners with Imec means that the company has an active policy of outsourcing at least part of its research activities. So we automatically exclude companies who do all research internally. We did correct for having an own research team in the field of interest (and hence doing part of the R&D internally) as well as for the research quality of the internal team (by means of their patent applications in the field of interest).

**Sender and receiver behavior**

Another limitation is that the study focuses only on what the company can do in view of an existing set of competencies and routines at one particular research Centre, namely Imec. It would certainly be of interest to see whether the results can be repeated using datasets from other Research Centers, which will have different sender behavior towards the receiving companies. This is another direction for future research.

Another limitation is the fact that this study investigated only the barriers to knowledge transfer at the receiver side; therefore, it would be interesting to further study also the transmitter behavior.

**Quality of the R&D team ex-ante the R&D project**

A general limitation of our approach is that we only had a very rough indication of the quality of the R&D team at the beginning of the project. Future research should focus on having a more detailed scale to assess the quality of the R&D team at the start of a collaborative project as well as on expanding the number of projects which are taken into account.

**Causal inference**

Another limitation of the studies in this thesis are its cross-sectional design. Although the results reveal antecedents from organizational competencies on innovative outcome, causal inference is only implied in some places by the theory but cannot be proven as we don't look at developments over time. The finding that an integrated R&D team, where focal firms' R&D personnel physically sit together with the R&D personnel of the research organization they collaborate with, delivers much better knowledge transfer and a higher innovation outcome, might suffer from *reverse causality*. The theory development in this thesis implies that the reduced boundaries between the organizations and higher breadth and frequency of communication between the R&D personal from both parties are delivering these improvements. Hence it is recommended practice for focal firms that have lower architectural competencies as it will help them to transfer knowledge as well as improve architectural competencies over time by experiencing effective practices for knowledge build-up and transfer from the R&D organization. Theoretically it is not completely unthinkable that organizations that have higher architectural competencies also realize themselves earlier that sitting physically closer together is improving knowledge transfer and hence will invest sooner and more often in creating an integral R&D team. However having been involved myself as R&D manager in many of such integral R&D projects, I believe the theory presented in this thesis that an integral R&D team increases architectural competencies over time rather than being as sign of high prior architectural competencies to be true.

**Project level versus company level innovation pipeline and partnerships**

The contribution of the thesis is that it evaluated performance results at the project level which is data which is almost never available to investigate, as such expanding existing research. At the same time, this could be a severe limitation in the complete thesis, as looking at the project level without looking at projects' innovation pipeline or combined portfolio, which are tied together at the overarching business unit and company level, has restrictions. At the project level, partners and customers are selected by the product management team, but we must realize that critical suppliers, as well as lead customers, likely develop a long term relationship, or envision one for the future, endorsed by the executive management of the company. Both in case of finding a customer as well as a supplier as the MIP, our expectation is that this could be a part of a long term strategic collaboration endorsed by the executive management of a company with much investments in relational non-contractual safeguards to reduce transaction cost. As this study evaluates relationships at the project level, a study that would couple the project level with long term inter-organizational networks could shed further light on this.

All chapters in this thesis considered R&D objectives that have been decided upon ex-ante the start of the R&D project. Additionally, projects included in the study cannot be really seen as stand-alone projects; instead, they are part of a stage-gate development process existing of a portfolio of projects changing over time. Clearly, the R&D prime objective, has to do with market insights as well as with the specific phase of the development process. Hence, this R&D prime objective most likely has more history, both in terms of the phase of the stage-gate innovation process as well as the market approach at a company level, which are far beyond the level of an individual R&D project. Indeed, a company can always choose to produce new products quickly at the lowest cost or focus to have the highest product performance as differentiator. Future study should replicate the results at the project level with business and even organization level.

### Financial and risk implications

Overall, in this thesis, I make suggestions for practicing managers to build more architectural competencies, apply recombination where appropriate, and consider the use of integrated R&D teams, although all these measures have financial implications and usually add risk to the R&D project. For integrated R&D teams, besides the clear pros, spillover risks, efficiency, and cost are also clear cons. Recombination is known to increase the technical risks of R&D, making the end-product more performant when successful but at a higher risk of not having a product in time at all (Collinson & Liu, 2017; Karim & Kaul, 2015). This study did not address any of the financial or risk implications associated with internal R&D involvement, recombination, or outsourcing of certain development. However, concepts like R&D performance and innovativeness have been linked to financial performance increase in earlier research (Kostopoulos, Papalexandris, Papachroni, & Ioannou, 2011; Wales, Parida, & Patel, 2013).

## Conclusion

This dissertation advances our understanding of how organizational competencies and R&D objectives are related with R&D partner selection and innovation performance. In the last decades, scholars have intensively investigated the ways in which external knowledge can be used to gain a competitive advantage (Berchicci, 2013; Caloghirou, Kastelli, & Tsakanikas, 2004; Crescenzi & Gagliardi, 2018). This thesis aimed to extend the innovation management literature by adding a combined RBV and RDT view enhanced with practical experience in the processes used within large companies to facilitate innovation management. These processes aim to make decisions more predictable in an environment of high uncertainty such as a gated innovation process, technical competence management and ex ante R&D objectives. The intended R&D prime objective and component competencies of the focal firm's team, and with that the (perceived) knowledge distance prior to an R&D project startup are found to be instrumental in the selection of its R&D partners which coincides with the traditional RBV. For partnership selection recombination, i.e. the ability to do substantial performance-enhancing modifications to both existing internal knowledge components as well as external knowledge components, seems to be the only architectural competency to be taken into account for partner selection explicitly. Absorptive capacity and width and frequency of interaction don't seem to be taken into account as input to partner selection much, even though they are instrumental for later innovation performance of collaborative R&D projects. This thesis shows that partner selection is a more complicated trade-off process than singular selection of partners by highlighting a new concept of the most important R&D partner, the partner whose resources are such, that they can be dominant when needed to decide on aspects of the product specification. This is where RDT comes in to expand the RBV, as the most important partner is the partner which is, in view of the focal firm, instrumental for the product success and cannot be replaced by e.g. building in redundancy. The most important partner by default is the focal firm itself, but in certain cases a key customer or a critical supplier can take on this role.

This thesis adds to the RBV theory the idea that the remaining knowledge distance is not formed by the relative distance to the component competencies of the focal firm but by the relative distance to the sum of the focal firm and its trusted partners component competencies. The assimilation and integration of external technology in the focal firm's technology base is highly dependent on the absorptive capacity and recombination competence of the focal firm. Therefore we find that the actual R&D performance during pre-product development innovation projects depends on the architectural competencies and the component competencies of the focal firm Especially the interaction of architectural competencies on component competencies is of great importance here. Higher component competencies alone in the field of knowledge of the external partner can even lead to worse innovation performance when not compensated by high architectural competencies. During collaborative pre-product R&D projects lower architectural competencies can be overcome by forming integrated R&D teams. This comes at a high cost though, both direct costs (the employees of the focal firm have to spend time at the research partner's premises), as indirect costs in the form of potential spillover risks to the research organization. This is more interesting when both architectural as well as component competencies of the focal firm are low, hence the risk of spillover to the research organization in terms of component competencies are automatically low as well. The role of the focal firm's component competencies in R&D performance is shown to reduce in importance later in the R&D process cycle, to become almost neglectable during the actual product development when trusted R&D partnerships are build and the focal firm has sufficient absorptive capacity. By the time that actual product development takes place the R&D performance is dominated by architectural competencies. This does not mean however that component competencies are unimportant and can be neglected; I see this rather as a proof that companies are rather good in estimating their own and their partner's component competencies and hence make sure that the overall combination of component competencies internally and of trusted partners is high enough to bridge the knowledge gap before starting product development. Architectural competencies always help in R&D performance, no matter if it is pre-product development or product development and they are moderated by R&D prime objective choices such as the project strategy and the decision to outsource or not.

In closing, this thesis highlights the importance of architectural competencies on R&D performance in a world where R&D partnering is key for company survival. At the same time, this thesis uncovers that architectural competencies are much less (explicitly) taken into account in the fundamental decision of R&D partner selection. It would be worthwhile to spend more research attention to how architectural competencies should ideally influence the R&D partner selection and way of working in collaborative R&D projects, just as there is also merit in defining a better framework and better scales to measure architectural competencies. This would automatically also lead to insights for practitioners on how to measure and manage the architectural competencies in their organization better. I believe that in a world of growing R&D complexity working with external R&D partners only becomes more essential, these future research avenues are well warranted.

# Bibliography


Abramowitz, M. a. S., I.A. (1965). *Handbook of Mathematical Functions.* . New York: Dover.

Agrawal, A., Cockburn, I., & Rosell, C. (2010). Not Invented Here? Innovation in company towns. *Journal of Urban Economics, 67*(1), 78-89. doi:10.1016/j.jue.2009.10.004

Anderson, J. C., & W., G. D. (1988). Structural Equation Modeling in Practice: A Review and Recommended Two-Step Approach. *Psychological Bulletin, 103*, 411-423.

Antons, D., & Piller, F. T. (2014). Opening the Black Box of "Not Invented Here": Attitudes, Decision Biases, and Behavioral Consequences. *Academy of Management Perspectives, 29*(2), 193-217. doi:10.5465/amp.2013.0091

Armstrong, J. S. a. O., Terry S., . (1977). Estimating Nonresponse Bias in Mail Surveys. *Journal of Marketing Research, 14*, 396-402. Retrieved from Available at SSRN: https://ssrn.com/abstract=659542

Atuahene-Gima, K., & Li, H. (2004). Strategic Decision Comprehensiveness and New Product Development Outcomes in New Technology Ventures. *Academy of Management Journal, 47*(4), 583-597. doi:10.5465/20159603

Bapuji, H., & Crossan, M. (2004). From Questions to Answers: Reviewing Organizational Learning Research. *Management Learning, 35*(4), 397-417. doi:10.1177/1350507604048270

Beckman, C. M., Haunschild, P. R., & Phillips, D. J. (2004). Friends or strangers? Firm-specific uncertainty, market uncertainty, and network partner selection. *Organization Science, 15*(3), 259-275. doi:DOI 10.1287/orsc.1040.0065

Berchicci, L. (2013). Towards an open R&D system: Internal R&D investment, external knowledge acquisition and innovative performance. *Research Policy, 42*(1), 117-127. doi:https://doi.org/10.1016/j.respol.2012.04.017

Bierly, P., & Chakrabarti, A. (1996). Determinants of technology cycle time in the U.S. pharmaceutical industry’. *R&D Management, 26*(2), 115-126. doi:10.1111/j.1467-9310.1996.tb00936.x

Bönte, W. K., M. (2005). Concubinage or marriage? Informal and formal cooperations for innovation. *International Journal of Industrial Organization, Volume 23*(3-4), 279-302. doi:https://doi.org/10.1016/j.ijindorg.2005.01.007.

Brockhoff, K. (2003). A utopian view of R&D functions. *R&D Management, 33*(1), 31-36. doi:10.1111/1467-9310.00279

Bryan Jean, R.-J., Sinkovics, R. R., & Kim, D. (2017). Antecedents and Outcomes of Supplier Innovativeness in International Customer–Supplier Relationships: The Role of Knowledge Distance. *Management International Review, 57*(1), 121-151. doi:10.1007/s11575-016-0291-x

Burcharth, A. L. d. A., Knudsen, M. P., & Søndergaard, H. A. (2014). Neither invented nor shared here: The impact and management of attitudes for the adoption of open innovation practices. *Technovation, 34*(3), 149-161. doi:10.1016/j.technovation.2013.11.007

Caloghirou, Y., Kastelli, I., & Tsakanikas, A. (2004). Internal capabilities and external knowledge sources: complements or substitutes for innovative performance? *Technovation, 24*(1), 29-39.

Campbell, A. J., & Cooper, R. G. (1999). Do Customer Partnerships Improve New Product Success Rates? *Industrial Marketing Management, 28*(5), 507-519. doi:http://dx.doi.org/10.1016/S0019-8501(99)00058-9

Cassiman, B., & Veugelers, R. (2002). R&D cooperation and spillovers: some empirical evidence from Belgium. *American Economic Review, 92*(4), 1169-1184.

Cassiman, B., & Veugelers, R. (2006). In search of complementarity in innovation strategy: Internal R&D and external knowledge acquisition. *Management Science, 52*(1), 68-82.

Chen, Y.-S., Lin, M.-J. J., & Chang, C.-H. (2009). The positive effects of relationship learning and absorptive capacity on innovation performance and competitive advantage in industrial markets. *Industrial Marketing Management, 38*(2), 152-158. doi:10.1016/j.indmarman.2008.12.003

Chesbrough. (2003). A better way to innovate. *Harv Bus Rev, 81*(7), 12-13, 115. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/12858705

Chesbrough. (2006). *Open Innovation: The New Imperative for Creating and Profiting from Technology*: Harvard Business School Press.

Chesbrough, & Crowther. (2006). Beyond high tech: early adopters of open innovation in other industries. *R & D Management, 36*(3), 229-236. doi:DOI 10.1111/j.1467-9310.2006.00428.x

Chesbrough, & Garman. (2009). How Open Innovation Can Help You Cope in Lean Times. *Harvard business review, 87*(12), 68-+. Retrieved from <Go to ISI>://WOS:000271933500016

Classen, N., Van Gils, A., Bammens, Y., & Carree, M. (2012). Accessing Resources from Innovation Partners: The Search Breadth of Family SMEs. *Journal of Small Business Management, 50*(2), 191-215. doi:10.1111/j.1540-627X.2012.00350.x

Cockburn, I. M., & Henderson, R. M. (1998). Absorptive capacity, coauthoring behavior, and the organization of research in drug discovery. *The Journal of Industrial Economics, 46*(2), 157-182.

Cohen, & Levinthal. (1989). Innovation and learning: the two faces of R & D. *The economic journal, 99*(397), 569-596.

Cohen, & Levinthal. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly, 35*(1), 128-152.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences (2nd Edition).* Hillsdale, NJ: Lawrence Earlbaum Associates.

Collins, J. D., & Hitt, M. A. (2006). Leveraging tacit knowledge in alliances: The importance of using relational capabilities to build and leverage relational capital. *Journal of Engineering and Technology Management, 23*(3), 147-167. doi:10.1016/j.jengtecman.2006.06.007

Collinson, S., & Liu, Y. (2017). Recombination for innovation: performance outcomes from international partnerships in China. *R&D Management, 49*(1), 46-63.

Cook, S. D., & Brown, J. S. (1999). Bridging epistemologies: The generative dance between organizational knowledge and organizational knowing. *Organization Science, 10*(4), 381-400.

Coombs, R. (1996). Core competencies and the strategic management of R&D. *R&D Management, 26*(4), 345-355.

Cooper, R. G. (1994). Third‐generation new product processes. *Journal of Product Innovation Management, 11*(1), 3-14.

Crescenzi, R., & Gagliardi, L. (2018). The innovative performance of firms in heterogeneous environments: The interplay between external knowledge and internal absorptive capacities. *Research Policy, 47*(4), 782-795. doi:10.1016/j.respol.2018.02.006

Cyert, R. M. (1963). *A behavioral theory of the firm [by] Richard M. Cyert [and] James G. March. With contributions by G. P. E. Clarkson [and others]*. Englewood Cliffs, N.J: Prentice-Hall.

Cyert, R. M., & March, J. G. (1992). *Behavioral Theory of the Firm 2nd Edition*: Wiley-Blackwell; 2 edition (July 27, 1992).
de Jong, J. P. J., & von Hippel, E. (2009). Transfers of user process innovations to process equipment producers: A study of Dutch high-tech firms. *Research Policy, 38*(7), 1181-1191. doi:https://doi.org/10.1016/j.respol.2009.04.005
Dekker, H. C. (2008). Partner selection and governance design in interfirm relationships. *Accounting, Organizations and Society, 33*(7-8), 915-941. doi:10.1016/j.aos.2007.02.002
Diestre, L., & Rajagopalan, N. (2012). Are all 'sharks' dangerous? new biotechnology ventures and partner selection in R&D alliances. *Strategic Management Journal, 33*(10), 1115-1134. doi:10.1002/smj.1978
Dillman, D. A., Smyth, J. D., & Christian, L. M. (2008). *Internet, Mail, and Mixed-Mode Surveys: The Tailored Design Method*: John Wiley & Sons.
Dussauge, P., Garrette, B., & Mitchell, W. (2000). Learning from Competing Partners: Outcomes and Durations of Scale and Link Alliances in Europe, North America and Asia. *Strategic Management Journal, 21*(2), 99-126. Retrieved from http://www.jstor.org/stable/3094036
Dyer. (1997). Effective interim collaboration: how firms minimize transaction costs and maximise transaction value. *Strategic Management Journal, 18*(7), 535-556.
Dyer, Kale, & Singh. (2001). How to make strategic alliances work. *MIT Sloan management review, 42*(4), 37-43. Retrieved from <Go to ISI>://WOS:000169844500012
Dyer, & Singh. (1998). The relational view: Cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review, 23*(4), 660-679. doi:Doi 10.2307/259056
EARTO. (2014). *The TRL Scale as a Research & Innovation Policy Tool, EARTO Recommendations*. Retrieved from http://www.earto.eu/fileadmin/content/03_Publications/The_TRL_Scale_as_a_R_I_Policy_Tool_-_EARTO_Recommendations_-_Final.pdf
Ebersberger, B., & Herstad, S. J. (2011). Product Innovation and the Complementarities of External Interfaces. *European Management Review, 8*(3), 117-135. doi:10.1111/j.1740-4762.2011.01014.x
Eccles, M., Smith, J., Tanner, M., Van Belle, J.-P., & Van Der Watt, S. (2010). Collocation Impact on Team Effectiveness. *South African Computer Journal, 46*. doi:10.18489/sacj.v46i0.54
Eisenhardt, K. M., & Martin, J. A. (2000). Dynamic capabilities: what are they? *Strategic Management Journal, 21*(10 - 11), 1105-1121.
Emden, Z., Calantone, R. J., & Droge, C. (2006). Collaborating for new product development: Selecting the partner with maximum potential to create value. *Journal of Product Innovation Management, 23*(4), 330-341. doi:DOI 10.1111/j.1540-5885.2006.00205.x
Expósito-Langa, M., Molina-Morales, F. X., & Capo-Vicedo, J. (2011). New product development and absorptive capacity in industrial districts: a multidimensional approach. *Regional Studies, 45*(3), 319-331.
Field, A. (2013). *Discovering Statistics Using IBM SPSS Statistics*: SAGE.
Flatten, T. C., Engelen, A., Zahra, S. A., & Brettel, M. (2011). A measure of absorptive capacity: Scale development and validation. *European Management Journal, 29*(2), 98-116. doi:10.1016/j.emj.2010.11.002
Galbreath, J. (2006). Corporate social responsibility strategy: strategic options, global considerations. *Corporate Governance: The international journal of business in society, 6*(2), 175-187.

Gann, D. M. (2005). H. Chesbrough, Open Innovation: The New Imperative For Creating And Profiting From Technology, Harvard Business School Press, 2003 (272 pp., $35.00, ISBN: 1-57851-837-7). *Research Policy, 34*(1), 122-123.

Gassmann, O., Enkel, E., & Chesbrough, H. (2010). The future of open innovation. *R&D Management, 40*(3), 213-221. doi:10.1111/j.1467-9310.2010.00605.x

Gomes-Casseres, B. (1997). Alliance strategies of small firms. *Small Business Economics, 9*(1), 33-44.

Gomes-Casseres, B. (2003). Competitive advantage in alliance constellations. In: Sage Publications.

Grant, R. M. (1996). Toward a knowledge-based theory of the firm. *Strategic Management Journal, 17*(S2), 109-122. doi:10.1002/smj.4250171110

Grant, R. M., & Baden-Fuller, C. (2004). A Knowledge Accessing Theory of Strategic Alliances. *Journal of Management Studies, 41*(1), 61-84. doi:10.1111/j.1467-6486.2004.00421.x

Griffin, A. (1993). Metrics for Measuring Product Development Cycle Time. *Journal of Product Innovation Management, 10*(2), 112-125. doi:10.1111/1540-5885.1020112

Griffith, D. A., & Harvey, M. G. (2004). The influence of individual and firm level social capital of marketing managers in a firm’s global network. *Journal of World Business, 39*(3), 244-254.

Grosse Kathoefer, D., & Leker, J. (2010). Knowledge transfer in academia: an exploratory study on the Not-Invented-Here Syndrome. *The Journal of Technology Transfer, 37*(5), 658-675. doi:10.1007/s10961-010-9204-5

Gruber, M., MacMillan, I. C., & Thompson, J. D. (2012). From minds to markets: How human capital endowments shape market opportunity identification of technology start-ups. *Journal of Management, 38*(5), 1421-1449.

Gryna, F. M., & Juran, J. M. (2001). *Quality planning and analysis: from product development through use*: McGraw-Hill New York.

Gulati, R., & Sytch, M. (2007). Dependence Asymmetry and Joint Dependence in Interorganizational Relationships: Effects of Embeddedness on a Manufacturer's Performance in Procurement Relationships. *Administrative Science Quarterly, 52*(1), 32-69. doi:10.2189/asqu.52.1.32

Gupta, A. K., & Govindarajan, V. (2000). Knowledge flows within multinational corporations. *Strategic Management Journal, 21*(4), 473-496. doi:10.1002/(sici)1097-0266(200004)21:4<473::Aid-smj84>3.0.Co;2-i

Hagedoorn, J. (2002). Inter-firm R&D partnerships: an overview of major trends and patterns since 1960. *Research Policy, 31*(4), 477-492. doi:https://doi.org/10.1016/S0048-7333(01)00120-2

Hagedoorn, J., Link, A. N., & Vonortas, N. S. (2000). Research partnerships. *Research Policy, 29*(4), 567-586. doi:https://doi.org/10.1016/S0048-7333(99)00090-6

Handfield, R. B., Ragatz, G. L., Petersen, K. J., & Monczka, R. M. (1999). Involving Suppliers in New Product Development. *California Management Review, 42*(1), 59-82. doi:10.2307/41166019

Henderson, R., & Cockburn, I. (1994). Measuring competence? Exploring firm effects in pharmaceutical research. *Strategic Management Journal, 15*(S1), 63-84.

Herzog, P., & Leker, J. (2010). Open and closed innovation–different innovation cultures for different strategies. *International Journal of Technology Management, 52*(3/4), 322-343.

Hillman, A. J., Withers, M. C., & Collins, B. J. (2009). Resource Dependence Theory: A Review. *Journal of Management, 35*(6), 1404-1427. doi:10.1177/0149206309343469

Hippel, E. v. (1998). Economics of Product Development by Users: The Impact of “Sticky” Local Information. *Management Science, 44*(5), 629-644. doi:10.1287/mnsc.44.5.629
Homburg, G. a. (2000). Does Customer Interaction Enhance New Product Success? *Journal of Business Research, 49*.
Kahn, W. A., Barton, M. A., & Fellows, S. (2013). Organizational Crises and the Disturbance of Relational Systems. *Academy of Management Review, 38*(3), 377-396. doi:10.5465/amr.2011.0363
Karim, S., & Kaul, A. (2015). Structural Recombination and Innovation: Unlocking Intraorganizational Knowledge Synergy Through Structural Change. *Organization Science, 26*(2), 439-455. doi:10.1287/orsc.2014.0952
Kathoefer, D. G., & Leker, J. (2012). Knowledge transfer in academia: an exploratory study on the Not-Invented-Here Syndrome. *The Journal of Technology Transfer, 37*(5), 658-675.
Katz, R., & Allen, T. J. (1982). Investigating the Not Invented Here (NIH) syndrome: A look at the performance, tenure, and communication patterns of 50 R & D Project Groups. *R&D Management, 12*(1), 7-20.
Keeter, S., Kennedy, C., Dimock, M., Best, J., & Craighill, P. (2006). Gauging the Impact of Growing Nonresponse on Estimates From a National RDD Telephone Survey. *Special Issue, 70*, 759-779. doi:10.1093/poq/nfl035
Kerssens‐van Drongelen, I. c., & Bilderbeek, J. (1999). R&D performance measurement: more than choosing a set of metrics. *R&D Management, 29*(1), 35-46.
Kesteloot, K., & Veugelers, R. (1995). Stable R&D cooperation with spillovers. *Journal of Economics & Management Strategy, 4*(4), 651-672.
Kim, L. (1997). The Dynamics of Samsung's Technological Learning in Semiconductors. *California Management Review, 39*(3), 86-100. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=bsh&AN=9708123176&site=ehost-live
Kline, S. J., & Rosenberg, N. (1986). An overview of innovation. *The positive sum strategy: Harnessing technology for economic growth, 14*, 640.
Kobarg, S., Stumpf-Wollersheim, J., & Welpe, I. M. (2017). University-industry collaborations and product innovation performance: the moderating effects of absorptive capacity and innovation competencies. *The Journal of Technology Transfer*. doi:10.1007/s10961-017-9583-y
Kostopoulos, K., Papalexandris, A., Papachroni, M., & Ioannou, G. (2011). Absorptive capacity, innovation, and financial performance. *Journal of Business Research, 64*(12), 1335-1343. doi:10.1016/j.jbusres.2010.12.005
Kostova, T., & Roth, K. (2002). Adoption of an organizational practice by subsidiaries of multinational corporations: Institutional and relational effects. *Academy of Management Journal, 45*(1), 215-233.
Ku, E. C. S., Wu, W.-C., & Chen, Y. J. (2016). The relationships among supply chain partnerships, customer orientation, and operational performance: the effect of flexibility. *Information Systems and e-Business Management, 14*(2), 415-441. doi:10.1007/s10257-015-0289-0
Laursen, K., & Salter, A. (2006). Open for innovation: the role of openness in explaining innovation performance among U.K. manufacturing firms. *Strategic Management Journal, 27*(2), 131-150. doi:10.1002/smj.507
Lazarotti, & Manzini. (2009). Different modes of open innovation: a theoretical framework and an emperical study. *International Journal of Innovation Management, 13*(04), 615-636. doi:10.1142/s1363919609002443

Leiponen, A., & Helfat, C. E. (2010). Innovation objectives, knowledge sources, and the benefits of breadth. *Strategic Management Journal, 31*(2), 224-236. doi:10.1002/smj.807

Levinthal, D. A., & March, J. G. (1993). The myopia of learning. *Strategic Management Journal, 14*(S2), 95-112. doi:10.1002/smj.4250141009

Lhuillery, S., & Pfister, E. (2009). R&D cooperation and failures in innovation projects: Empirical evidence from French CIS data. *Research Policy, 38*(1), 45-57. doi:10.1016/j.respol.2008.09.002

Li, H., & Atuahene-Gima, K. (2001). Product innovation strategy and the performance of new technology ventures in China. *Academy of Management Journal, 44*(6), 1123-1134.

Lichtenthaler, U. (2009). Absorptive Capacity, Environmental Turbulence, and the Complementarity of Organizational Learning Processes. *The Academy of Management Journal, 52*(4), 822-846. Retrieved from http://www.jstor.org/stable/40390318

Lindgren, R., Henfridsson, O., & Schultze, U. (2004). Design principles for competence management systems: a synthesis of an action research study. *MIS quarterly*, 435-472.

Liyanage, S., & Barnard, R. (2003). Valuing of firms' prior knowledge: a measure of knowledge distance. *Knowledge and Process Management, 10*(2), 85-98.

Maes, J., & Sels, L. (2014). SMEs' Radical Product Innovation: The Role of Internally and Externally Oriented Knowledge Capabilities. *Journal of Small Business Management, 52*(1), 141-163. doi:10.1111/jsbm.12037

Mahoney, J. T., & Williams, C. (2003). Sticky Knowledge: Barriers to Knowing in the Firm. *Academy of Management Review, 28*(4), 679-681. doi:10.5465/amr.2003.10899477

Makri, M., Hitt, M. A., & Lane, P. J. (2010). Complementary technologies, knowledge relatedness, and invention outcomes in high technology mergers and acquisitions. *Strategic Management Journal, 31*(6), 602-628. doi:10.1002/smj.829

March, J. G. (1991). Exploration and Exploitation in Organizational Learning. *Organization Science, 2*(1), 71-87. doi:10.1287/orsc.2.1.71

Martin, & Salomon. (2003). Knowledge transfer capacity and its implications for the theory of the multinational corporation. *Journal of International Business Studies, 34*(4), 356-373.

Martin, Salomon, & Wu. (2010). The institutional determinants of agglomeration: a study in the global semiconductor industry. *Industrial and Corporate Change, 19*(6), 1769-1800. doi:10.1093/icc/dtq049

McIvor, R. (2009). How the transaction cost and resource-based theories of the firm inform outsourcing evaluation. *Journal of Operations Management, 27*(1), 45-63. doi:https://doi.org/10.1016/j.jom.2008.03.004

Mendonça Natalino Zenun, M., Loureiro, G., & de Araujo Junior, C. (2007). The Effects of Teams' Co-location on Project Performance. doi:10.1007/978-1-84628-976-7_79

Menguc, B., & Auh, S. (2006). Creating a firm-level dynamic capability through capitalizing on market orientation and innovativeness. *Journal of the Academy of Marketing Science, 34*(1), 63. doi:10.1177/0092070305281090

Miotti, L., & Sachwald, F. (2003). Co-operative R&D: why and with whom? *Research Policy, 32*(8), 1481-1499. doi:10.1016/s0048-7333(02)00159-2

Mom, T. J. M., Van Den Bosch, F. A. J., & Volberda, H. W. (2007). Investigating Managers' Exploration and Exploitation Activities: The Influence of Top-Down, Bottom-Up, and Horizontal Knowledge Inflows*. *Journal of Management Studies, 44*(6), 910-931. doi:10.1111/j.1467-6486.2007.00697.x

Morgan, R. E., & Berthon, P. (2008). Market Orientation, Generative Learning, Innovation Strategy and Business Performance Inter-Relationships in Bioscience Firms. *Journal of Management Studies, 45*(8), 1329-1353. doi:10.1111/j.1467-6486.2008.00778.x

Mortara, L., & Minshall, T. (2011). How do large multinational companies implement open innovation? *Technovation, 31*(10-11), 586-597. doi:10.1016/j.technovation.2011.05.002

Murovec, N., & Prodan, I. (2009). Absorptive capacity, its determinants, and influence on innovation output: Cross-cultural validation of the structural model. *Technovation, 29*(12), 859-872. doi:10.1016/j.technovation.2009.05.010

Muthen, M. a. (2015). MPLUS 7.4. Los Angelos.

Myles Shaver, J., & Flyer, F. (2000). Agglomeration economies, firm heterogeneity, and foreign direct investment in the United States. *Strategic Management Journal, 21*(12), 1175-1193.

Nadler, J., Thompson, L., & Boven, L. V. (2003). Learning negotiation skills: Four models of knowledge creation and transfer. *Management Science, 49*(4), 529-540.

Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science, 5*(1), 14-37.

Nonaka, I., & Von Krogh, G. (2009). Perspective—Tacit knowledge and knowledge conversion: Controversy and advancement in organizational knowledge creation theory. *Organization Science, 20*(3), 635-652.

Noordhoff, C. S., Kyriakopoulos, K., Moorman, C., Pauwels, P., & Dellaert, B. G. (2011). The bright side and dark side of embedded ties in business-to-business innovation. *Journal of Marketing, 75*(5), 34-52.

Orlikowski, W. J. (2002). Knowing in practice: Enacting a collective capability in distributed organizing. *Organization Science, 13*(3), 249-273.

Ortt, J. R., & Smits, R. (2006). Innovation management: different approaches to cope with the same trends. *International Journal of Technology Management, 34*(3-4), 296-318.

Ozcan, P., & Eisenhardt, K. M. (2009). Origin of Alliance Portfolios: Entrepreneurs, Network Strategies, and Firm Performance. *Academy of Management Journal, 52*(2), 246-279. doi:10.5465/amj.2009.37308021

Peeters, T. J. G. (2013). *External knowledge search and use in new product development.* (PhD PhD). Tilburg university, Tilburg.

Pfeffer, J., & Salancik, G. R. (1978). *The external control of organizations : a resource dependence perspective*. New York: Harper & Row.

Piga, C., & Poyago-Theotoky, J. (2004). Endogenous R&D spillovers and locational choice with discriminatory pricing. *Managerial and Decision Economics, 25*(3), 157-161. doi:10.1002/mde.1137

Poot, T., Faems, D., & Vanhaverbeke, W. (2009). Toward a dynamic perspective on open innovation: A longitudinal assessment of the adoption of internal and external innovation strategies in the Netherlands. *International Journal of Innovation Management, 13*(02), 177-200.

Porter, M. E., Porter, M., E, P. M., & Texts, A. S. C. o. M. (1985). *Competitive Advantage: Creating and Sustaining Superior Performance*: Free Press.

Praest Knudsen, M., & Bøtker Mortensen, T. (2011). Some immediate – but negative – effects of openness on product development performance. *Technovation, 31*(1), 54-64. doi:http://dx.doi.org/10.1016/j.technovation.2010.07.002

Questel. (2015). Orbit Intelligence: Questel.

Rebolledo, C., Halley, A., & Nagati, H. *The effects of absorptive capacity on operational performance within the context of customer-supplier relationships*. Retrieved from https://ideas.repec.org/p/hal/journl/hal-00814143.html

Rechtin, E., & Maier, M. W. (1997). *The Art of Systems Architecting*: Taylor & Francis.

Reed, R., Storrud‐Barnes, S., & Jessup, L. (2012). How open innovation affects the drivers of competitive advantage Trading the benefits of IP creation and ownership for free invention. *Management Decision $V 50*(1), 58-73.

Reuer, J. J., & Devarakonda, R. (2017). Partner Selection in R&D Collaborations: Effects of Affiliations with Venture Capitalists. *Organization Science, 28*(3), 574-595. doi:10.1287/orsc.2017.1124

Roberts, E. B. (2001). Benchmarking global strategic management of technology. *Research-Technology Management, 44*(2), 25-36.

Rosenberg, N. (1990). Why do firms do basic research (with their own money)? *Research Policy, 19*(2), 165-174. doi:https://doi.org/10.1016/0048-7333(90)90046-9

Rosenkopf, L., & Almeida, P. (2003). Overcoming local search through alliances and mobility. *Management Science, 49*(6), 751-766.

Rosenkopf, L., & Nerkar, A. (2001). Beyond local search: boundary-spanning, exploration, and impact in the optical disk industry. *Strategic Management Journal, 22*(4), 287-306. doi:10.1002/smj.160

Rothwell, R. (1977). The characteristics of successful innovators and technically progressive firms (with some comments on innovation research). *R&D Management, 7*(3), 191-206. doi:10.1111/j.1467-9310.1977.tb01334.x

Rothwell, R., & Gardiner, P. (1985). Invention, innovation, re-innovation and the role of the user: A case study of British hovercraft development. *Technovation, 3*(3), 167-186. doi:https://doi.org/10.1016/0166-4972(85)90012-4

Roussel, P., Saad, K., & Erickson, T. (1991). Third generation R&D management. *Harvard Business School Press, Boston*.

Ryzhkova, N., & Pesamaa, O. (2015). Absorptive capacity, collaboration with customers and innovation performance of gazelle companies in knowledge-intensive industries. *International Journal of Innovation Management, 19*(05), 1550059. doi:10.1142/s1363919615500590

Schmiedeberg, C. (2008). Complementarities of innovation activities: An empirical analysis of the German manufacturing sector. *Research Policy, 37*(9), 1492-1503. doi:http://dx.doi.org/10.1016/j.respol.2008.07.008

Schuhmacher, A., Germann, P.-G., Trill, H., & Gassmann, O. (2013). Models for open innovation in the pharmaceutical industry. *Drug Discovery Today, 18*(23), 1133-1137. doi:https://doi.org/10.1016/j.drudis.2013.07.013

Scott, W. (1998). Organizations: Rational, Natural and Open Systems. *Canadian Journal of Sociology / Cahiers canadiens de sociologie, 29*. doi:10.2307/2393090

Sethi, R. (2000). New product quality and product development teams. *Journal of Marketing, 64*(2), 1-14.

Shan, W., Walker, G., & Kogut, B. (1994). Interfirm cooperation and startup innovation in the biotechnology industry. *Strategic Management Journal, 15*(5), 387-394.

Sharot, T. (2011). The optimism bias. *Current Biology, 21*(23), R941-R945. doi:https://doi.org/10.1016/j.cub.2011.10.030

Shaw, B. (1994). *User-supplier links and innovation*.

Som, O., Kirner, E., & Jäger, A. (2015). The Absorptive Capacity of Non-R&D-Intensive Firms. In O. Som & E. Kirner (Eds.), *Low-tech Innovation: Competitiveness of the German Manufacturing Sector* (pp. 145-164). Cham: Springer International Publishing.

Soper, D. S. (2017). A-priori Sample Size Calculator for Multiple Regression (Software]. Retrieved from http://www.danielsoper.com/statcalc

Steensma, H. K., & Corley, K. G. (2001). Organizational Context as a Moderator of Theories on Firm Boundaries for Technology Sourcing. *The Academy of Management Journal, 44*(2), 271-291. doi:10.2307/3069455
Szulanski, G., Cappetta, R., & Jensen, R. J. (2004). When and How Trustworthiness Matters: Knowledge Transfer and the Moderating Effect of Causal Ambiguity. *Organization Science, 15*(5), 600-613. doi:10.1287/orsc.1040.0096
Szulanski, G., & Jensen, R. J. (2006). Presumptive adaptation and the effectiveness of knowledge transfer. *Strategic Management Journal, 27*(10), 937-957. doi:10.1002/smj.551
Teece. (2007). Explicicating dynamic capabilities. doi:10.1002/smj.64
Tidd, J., & Trewhella, M. J. (1997). Organizational and technological antecedents for knowledge acquisition and learning. *R&D Management, 27*(4), 359-375. doi:10.1111/1467-9310.00071
Todorova, G., & Durisin, B. (2007). Absorptive capacity: Valuing a reconceptualization. *Academy of Management Review, 32*(3), 774-786. doi:10.5465/amr.2007.25275513
Traitler, H., Watzke, H. J., & Saguy, I. S. (2011). Reinventing R&D in an open innovation ecosystem. *J Food Sci, 76*(2), R62-68. doi:10.1111/j.1750-3841.2010.01998.x
Ulrich, D., & Barney, J. B. (1984). Perspectives in Organizations: Resource Dependence, Efficiency, and Population. *Academy of Management Review, 9*(3), 471-481. doi:10.5465/amr.1984.4279680
Vanhaverbeke, W., Van de Vrande, V., & Cloodt, M. (2007). Connecting absorptive capacity and open innovation. *Available at SSRN 1091265*.
Vera, D., & Crossan, M. (2004). Strategic leadership and organizational learning. *Academy of Management Review, 29*(2), 222-240.
Veugelers, R. (1997). Internal R & D expenditures and external technology sourcing. *Research Policy, 26*(3), 303-315. doi:http://dx.doi.org/10.1016/S0048-7333(97)00019-X
Visser, P., Krosnick, J., Marquette, J., & Curtin, M. (1996). Mail Surveys for Election Forecasting? An Evaluation of the Columbus Dispatch Poll. *Public Opinion Quarterly, 60*, 181. doi:10.1086/297748
Von Hippel, E. (1978). A customer-active paradigm for industrial product idea generation. *Research Policy, 7*(3), 240-266. doi:https://doi.org/10.1016/0048-7333(78)90019-7
Vrande, V., P J De Jong, J., Vanhaverbeke, W., & De Rochemont, M. (2009). Open Innovation in SMEs: Trends, Motives and Management Challenges. *Technovation, 29*, 423-437. doi:10.1016/j.technovation.2008.10.001
Wagner, S. M., & Hoegl, M. (2006). Involving suppliers in product development: Insights from R&D directors and project managers. *Industrial Marketing Management, 35*(8), 936-943.
Wales, W. J., Parida, V., & Patel, P. C. (2013). Too much of a good thing? Absorptive capacity, firm performance, and the moderating role of entrepreneurial orientation. *Strategic Management Journal, 34*(5), 622-633. doi:10.1002/smj.2026
Wernerfelt, B. (1984). A resource‐based view of the firm. *Strategic Management Journal, 5*(2), 171-180.
Williams, C., & Lee, S. H. (2009). Exploring the internal and external venturing of large R&D‐intensive firms. *R&D Management, 39*(3), 231-246. doi:10.1111/j.1467-9310.2009.00553.x
Witzeman, S., Slowinski, G., Dirkx, R., Gollob, L., Tao, J., Ward, S., & Miraglia, S. (2006). Harnessing external technology for innovation. *Research-Technology Management, 49*(3), 19-27.

Xia, T. (2013). Absorptive capacity and openness of small biopharmaceutical firms–a E uropean U nion–U nited S tates comparison. *R&D Management, 43*(4), 333-351.
Zahra, S. A., & George, G. (2002). Absorptive capacity: A review, reconceptualization and extension. *Academy of Management Journal, 27*(2), 185-203.
Zahra, S. A., & Hayton, J. C. (2008). The effect of international venturing on firm performance: The moderating influence of absorptive capacity. *Journal of Business Venturing, 23*(2), 195-220. doi:http://dx.doi.org/10.1016/j.jbusvent.2007.01.001
Zander, U., & Kogut, B. (1995). Knowledge and the Speed of the Transfer and Imitation of Organizational Capabilities: An Empirical Test. *Organization Science, 6*(1), 76-92. doi:10.1287/orsc.6.1.76

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Still, the vast majority of time working on this manuscript I have so much enjoyed the possibility to do this, a possibility not only given to me by Xavier as my promotor, but also by my manager in Imec at the time, Bert Gyselinckx. It has been fantastic to step back from the daily business and dive deep into the academic field of innovation management and couple the academic and practitioners' world together. Xavier has given me so much direction and insights which I needed in order to make sense between what I know to be true in practice and the academic learnings in the field. I'm very grateful for his guidance and also for his attention to detail, which as a practicing manager I sometimes forget. I'm sure it was no picknick for him either, as our long discussions usually took place evenings and weekends, way outside any normal working hours. So thank you Xavier for this opportunity and your guidance through all these years from the bottom of my heart! I hope our collaboration will lead to future publications, as then it would finally also pay off for you to have done all this work. Niels Noorderhaven, my co-promotor whom I only met much more recently, I thank especially because of his strength in giving accurate high-level feedback. His comments on making Chapter 4 much more exploratory have really helped to bring my thoughts more together. Rik Pieters, Martin Goossen and Thijs Peeters, the other members of the promotion committee, have done their fair share as well: together they gave me no less than 15 pages of critical and well thought-through suggestions to improve the manuscript in front of you. Rik, who also taught me structural equation modelling, gave comments with a special focus on statistic rigor; Martin gave incredibly useful detailed feedback, especially on how to sharpen the research questions and embed the work much better in the existing literature. Thijs, for whom I'm so happy that he accepted to be on the committee as external member, because he helped me out when he was still a PhD student himself, by lending me the original questionnaire which he created. He focused in his comments on making the key points more visible and the work much more readable. Thank you all so much.

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[6] The presence of a "paranimf" during the public Ph.D. defense is a typical Dutch academic tradition. There are usually two of them and their role is to assist the Ph.D. student. In English it can be translated as paranymph, as the Ph.D. student becomes "married" to the academic world.

Without Imec this research would not have been possible. Besides my manager at the time Bert Gyselinckx and the executive management of Imec, who supported this work from day one, I'm incredibly grateful to the program, business and technical staff that helped me gather data and whom were interviewed about their experiences. There is no way I could have achieved this without my fantastic colleagues at Imec. My second "paranimf" is hence my longstanding colleague and dear friend Marianne Vandecasteele, who worked and works alongside me in a few decades of R&D collaborations: at Philips, Imec and now at ASML. The Imec IP department and specifically Kathleen de Belder was instrumental in the collecting and understanding of the patent data of Imec's partner companies used in Chapter 3 to validate the project innovation outcome. For the same Chapter, Vilma Sharma, now almost finished with her own PhD research, acted as research assistant. I got to know her as a smart and dedicated woman and believe she is headed for a great academic future! Inger Rempt helped me with the creation of the original on-line questionnaire used to collect the data for Chapter 2 and 4. I can't repeat enough how this thesis would have never materialized without the help of all these people.

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done. We are here for you to help you find out who you love and what you love. All we can ever ask of you is to dedicate yourself to who and what you love and hopefully enjoy your life while doing that!

## About the author

Harmke de Groot was born in Nijmegen, the Netherlands in 1974. After obtaining the VWO degree (pre-university high school education) in 1992, she started to study Electrical Engineering at the university of technology Eindhoven, the Netherlands. She did her graduation work at Philips Semiconductors on the design of the analog front-end of an ADSL modem. The joy of being at the frontend of new innovations, as high speed internet over twisted pairs actually still was in 1997, inspired a career in research and development. She joined Philips Semiconductors as design engineer and later system architect, working on the first generation of Bluetooth devices as well as the Bluetooth standard itself.

In 2001 she joined Philips Research as system architect making hardware and software trade-offs in distributed systems for scalable video streaming. As European project manager she set up and managed two European consortia focusing on ambient intelligence and real-time streaming solutions. As part of these collaborative R&D efforts, she co-authored a book on the impact of ambient intelligence on embedded system design as well as many papers.

The vision of ambient intelligence entails that devices work almost invisibly to support people in carrying out their everyday life activities, tasks and rituals. They interact with humans in an easy, natural way using information and intelligence that is hidden in the network connecting these devices, for example the Internet of Things (IoT). Semiconductor technology following Moore's law is one of the major enablers for ambient intelligence.

Working close with the European Microsoft Innovation Centre on ambient intelligence lead to her first innovation management position when she joined in 2006 as group program manager. In this role she was responsible for partnership management, setup & execution of new projects with external R&D partners as well as the value creation for Microsoft in terms of knowledge transfer and IP generation.

Starting in 2008 and continuing for nearly a decade, she was working at research organization Imec as R&D director. In the end she was responsible for the IoT program including all R&D done on wireless communication and sensing in both the Leuven as well as Eindhoven locations of Imec. With a direct P&L and people responsibility for ~130 researchers and more than 2/3 of R&D directly funded by industry, it was the perfect environment to notice how different firms are in dealing with collaborative R&D and how that impacted their innovation performance. With her team, she developed and maintained bilateral R&D projects with many industrial partners worldwide including Analog Devices, Global Foundries, Huawei, Sony, Infineon, Microsemi, Omron, Philips, Panasonic, Renesas and Samsung. On top of that there were R&D consortia involving a multitude of R&D partners.

As part of developing herself as an innovation leader, she did a part-time MBA program at the university of Tilburg, the Netherlands and graduated with distinction in 2013. Her thesis work on R&D partnerships & the industrial valorization thereof led to further discussions and sparked the idea of doing a PhD in innovation management and strategy, which she started in 2014 and where this thesis is the final product of.

In 2018 she moved back to the semiconductor industry and into machine building pushing Moore’s law further by becoming the manager of ASML’s electronics development team for the EUV Source functions.